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NAVAL CIVIL ENGINEERING LABORATORY
Port Hueneme, California

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HISTORICAL REVIEW OF VLF INSULATOR TESTS

July 1981

An Investigation Conducted by
ELECTROSPACE SYSTEMS, INC.
P. O. Box 6368
San Diego, California

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This report presents a historical overview of the intense VLF test program conducted from 1972 to 1976 at NAVCOMSTA Laulaulei, Hawaii. The report details the rationale for each test conducted and presents technical descriptions of the test items and reasons why some tests were incomplete, terminated, finished and/or modified during the test program.

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1.0 INTRODUCTION

The economics of Naval Communications have dictated that conventional vertically polarized Very Low Frequency/Low Frequency (VLF/LF) transmitting antennas are electrically short in terms of transmitted wavelength. The basic physics of such radiators implies that to accelerate charge sufficiently to radiate appreciable power, the structure must carry voltages of the order of several hundred thousand volts. Inevitably, insulators incorporated into such structures to withstand these potentials also play a significant structural role. Thus, the insulating components of high power VLF/LF transmitting antennas must satisfy almost unique requirements of high structural strength, high voltage withstand, high reliability, low dead weight, and low cost. The procurement of such devices therefore requires a breadth of engineering knowledge, background, and expertise in several diverse fields not ordinarily found in civil engineers who usually design the radiators, viewed primarily as structures.

Such a limitation of outlook led to a series of catastrophic failures of insulators incorporated in a number of VLF radiators designed and constructed in the late 1960's and early 1970's for Naval Communications and for the Omega Navigation System. These problems required an extensive series of investigations and redesign of insulators and associated hardware over a period of years, on what amounted to a crash basis due to the urgency imposed by the Chief of Naval Operations (CNO) on the

upgrade of both the communication and navigation capabilities for the Fleet to adequately accomplish its mission in today's political environment. The redesign and upgrade was accomplished by an almost pragmatic approach which was carried out with little documentation other than the reporting of message traffic, speedletters, and correspondence enclosures addressed at the time to the major participants. Little formal documentation was possible because of the press of time and limitations of funding. It is the purpose of this report to initiate a collection of this information into one place; in particular, this work provides an historical review of what took place in chronological order in the years 1972 to 1976. It does not give results in any detail since this is the subject for a subsequent effort.

It is noted that the present limitations on time and funding have made this overview into a document that is abbreviated and, in some cases, obscure to anyone who was not immediately and intimately associated with the tests of the devices described; also, the devices themselves at this remove are referred to in some cases, only in a highly colloquial manner. It will also be found that the account herein is, in part, highly personal, in view of the author's unique position, having served as Test Director, instigator, and, on occasion, gadfly. In some instances, the author had been involved as the employee of a contractor, prior to his function as a government critic, who made cost estimates and design recommendations of devices which subsequently failed. This is not to cast aspersions on himself or any associates, but only to remind the reader that at

the time that a lot of the design and procurement effort was going on, the best information that could be brought to bear reflected a high degree of ignorance about the distinction between power frequency and radio frequency environments which the program here being summarized, hopefully, in a large part removed. The motivation for the present work is to provide the information, heretofore deficient, and to prevent such future fiascoes.

An attempt has been made to provide literature references, but early in the writing of this account, it was realized that any attempt at completeness would yield a list of several hundred documents, the availability of most of which would be at least questionable. There is no intentional slighting of authors or sources. A few of the more relevant papers are mentioned. Titles of books will occur to those familiar with the field, such as those written by Cobine, Loeb, and F.W. Peek.

1.1 Electrically Short Antenna Characteristics

The problem confronted by the communications systems engineer is to provide an available link with less than an allowable maximum error rate for some minimum percentage of time in a predicted maximum noise environment in a specified coverage area (or range) for some modem using a defined rate of transmittal. To the transmitting antenna designer this implies a radiator and associated tuning, matching, and power amplifier circuits such as to give a maximum radiated power over a band of operating frequencies (for carrier and side bands) within some 3 dB bandwidth within a defined limit on voltage and cost. The structure also must occupy a fairly obviously defined piece of real estate and be realistically stressed for the physical environment which implies wind loads, ice loads, moisture precipitation rates, atmospheric electricity, earthquake hazards, temperature extremes, etc.

At frequencies such that the transmitting antenna can be conviently made comparable to a wavelength, it normally is not hard to arrive at a reasonable compromise to satisfy all conditions enumerated above simultaneously; the most stringent requirements usually are to provide coverage within and not beyond politically defined boundaries without interference outside, and so directionality is a factor. For Naval Communications and Navigation at VLF and LF, assuming broadcast capability at specified frequencies, these considerations are not factors. The most usual fight is to provide the coverage reliability in the reception area from a remotely placed source, in consideration of the noise fields at

the receiver. VLF has traditionally provided the most reliable long distance coverage with very low attenuation rates for the radio fields, but the wavelengths in the range of 10 kHz to 30 kHz mean that conveniently physically realizable structures are considerable smaller than a quarter of a wavelength in height. Height over the ground is an important consideration because the usual attenuation rates and coupling factors of energy into the earth-ionosphere waveguide favor the launching of vertically polarized waves. As indicated in the next section, height can be directly traded for operating voltage and so the structural limits can be, in part, made up by raising voltage limits.

Typically in the past, the operating voltage limit was about 200 kV to 250 kV at the Navy VLF stations. This limit was met satisfactorily by grounded-tower-supported top loads whose insulation was provided by hollow, tubular, smooth-surfaced "stick" strain insulators on which were imposed usual structural working loads of no more than 30,000 pounds. These insulators and their associated anticorona hardware evolved from design and testing programs carried out during and after World War I into the early twenties by W.W. Brown and others using a tuned circuit providing voltages at LF up to about 180 kV. By cascading two units which, with rather simple hardware qualified individually up to this limit for continuous arc-free operation, it was found that 250 kV could rather easily be obtained, and structural loads could be sustained in excess of the limits for single units by arranging them in parallel through the use of equalizing

yokes without significantly disturbing the electrical characteristics. Thus for years, and for designs not departing greatly from these early mechanical and electrical stress limits, the practical upper limit for operating voltage was regarded as given.

It is fairly easy to show that the remote (radiation) field of an electrically small vertical radiator measured at the ("perfectly" conducting) earth's surface, associated with vertical polarization, is given by the following very simple relationship, apart from propagation effects imposed by the presence of the earth-ionosphere waveguide:

$$H = E/\eta = \frac{I\ h_e}{\lambda\ d} \qquad (1)$$

in which I is the rms current at the feed point, λ is the wave length in free space, h_e is the so-called "effective height", d is the distance from the source to the observation point and η is the intrinsic impedance of space, 120 π ohms or approximately 377. In an electrically short radiator the impedance presented to the source is primarily capacitive and therefore the current is very nearly given by the ratio V/X, where X is simply the capacitive reactance of the antenna. Thus with a fixed upper limit on voltage, the current moment I h_e can be increased by either reducing the capacitive reactance (increasing the antenna capacity, by increasing the area of the topload) or by increasing the effective height; in the days of World War II and immediately before, upgrades of existing stations in consideration of the existence of more or less standard free-standing tower

designs consisted mainly by economic convenience in enlarging the area because the joint imposition of voltage rating for the insulators and the limits of the known tower design in supporting the topload conductors defined everything but the area factor in the antenna capacity.

Equation (1) can be taken as equivalently defining the power radiating capability of the source since the Poynting vector flux is $H^2 \eta$ in the remote field. With suitable accounting for the vertical pattern of a short monopole radiator, this can be expressed in terms of the radiation component of the resistive portion of the antenna impedance as

$$R_r = 160 \pi^2 (h_e/\lambda)^2 \tag{2}$$

where of course the resistance R_r is referred to the feed point as the ratio of radiated power to feed current squared.

Although important for pricing the performance from the standpoint of output versus input power, system performance is not described adequately until some accounting is made of information rate. In the earlier days of more or less tactical use of long range communication and with the limits imposed by the then-used method of on-off keying, the theoretical upper limit of communication rate was not realized and transmitting bandwidth was not a performace criterion to be concerned about except as it implied something about rise and decay times for the leading and trailing edges of the keyed waveform and the ability of the receive system to discriminate between successive transmissions of dots and dashes.

After WW II, with increased emphasis on reliability and transmission rate on a global (strategic) basis, especially with the advent of the FBM fleet and attendant C^3 requirements, the meeting of possible theoretical limits in information rate became important and FSK and MSK modems made such possible. Thus, the pricing of the transmitting system also had to reflect trades of the parameters implicit in the relationship for bandwidth B

$$B = f/Q, \quad Q = X_o/R \tag{3}$$

where $R = R_r + R_{loss}$ (series equivalent) f is the center operating frequency, and X_o is the antenna static capacity reactance related to base reactance X by $X = X_o\ (1 - f^2/f_o^{\ 2})$, f_o being self resonant frequency. As will become evident in what follows, this more or less new requirement imposed greater emphasis on physical height and on structural aspects in consequence, and the new modems put increased demands on electrical performance of insulators relating to withstand capability.

It is apparent from the above, stated more or less without proof, that viewed as a circuit element, a VLF/LF antenna looks like a lossy capacitor a portion of whose losses can be related to the radiation from a vertical current moment; the rest of the loss budget consists of copper or conduction loss in the current-carrying system.* Viewed as a source of radio energy, the VLF/LF antenna is a vertical current moment whose

* Dielectric type losses are usually so small as to be almost negligible.

magnitude is controlled by the capacity, voltage, and frequency; the inherent information rate is governed by the self capacity and the total energy loss. In an optimization process, all these aspects must be priced and balanced in terms of system performance. The developmental history of the Naval Communication system has made the practicable voltage limit to be about 250 kV (not as an absolute requirement), with a strong motivation to achieve this with higher ratios of strength to weight in view of all that this implies relative to the system cost.

1.2 Defining Equations for Short Antennas

Either through the use of a fairly recondite approach based on a mode-theoretical analysis of the antenna problem, or on a fairly simple-minded application of lumped circuit analysis, the above relationships can be transformed into the following set. These expressions are generally regarded by practitioners in the field as basic; it is well recognized that with suitable precautions, they can be used to carry out performance trades in an initial design approach, and when coupled with some fairly simple rules of thumb about pricing, can be used to give an initial approximation for installed cost, at least for early comparison purposes. The equations are:

$$P_r = k\ h_e^2\ V^2\ C_o^2\ f^4$$

$$B_{as} = (k/2\pi)\ C_o\ h_e^2\ f^4/\eta_{as} \qquad (4)$$

$$\eta_{as} = P_r/P_{as}$$

in which

$$k = 40\ (2\pi)^4/v_o^2, \quad v_o = 3 \times 10^8 \text{ meters per second}$$

$$= 6.93 \times 10^{-13}$$

All quantities in (4) are in MKSQ, i.e., meters, farads, volts, Hertz. The subscript as refers to "antenna system," and obviously efficiency η_{as} is radiation efficiency and makes a demand ultimately on the power capability of the generating source.

The "voltage" V must be regarded with a certain amount of trepidation as the average potential on the structure; in one that is infinitely small, there is no difficulty with definition, but in one of finite extent relative to a quarterwave there is a so-called "inductive rise" which simply means that because of distributed inductance in the antenna the feed voltage is not the same as that at the outer extremities. This voltage distribution can more or less be simply predicted; often it must be subjected to confirmatory experimental measurement. In any design situation, it can be regarded as definable and therefore implies definite requirements on insulator ratings when the locations of these are established by structural considerations.

It is sometimes the case for very short, heavily top-loaded configurations that most of the inductance can be regarded as residing in the "downlead" carrying current up to the capacitive top load, so that "the voltage" is that on the top load itself, provided most of the significant capacity elements are also in the top load. In such a situation, total antenna system input power is $P_{as} = I R_{as}$, where $I = V_{as}/X_o$, $V_{as} = V(1 - f^2/f_o^2)$, f_o being the self-resonant frequency.

The purely geometric quantity, bandwidth-efficiency product, or 100% efficiency bandwidth, is intrinsic to the antenna geometry and

so is fixed thereby through the relationship

$$B_{100} = B_{as} \; as = (k/2\pi) \; C_o \; h_e^2 \; f^4 \; . \qquad (5)$$

for a given operating frequency. On the other hand, although power handling capability is established in a similar way, except for a square-law dependence on capacity rather than a linear one, it is open-ended in the sense that, provided gradients can be controlled to levels below critical, radiated power is only limited by transmitter capability; that a practical limit for voltage and gradient may be reached is evident from the square-law involvement of voltage, and the realization that when disruptive breakdown is reached, any further increase in source energy only goes to sustain the discharge rather than produce information-bearing energy. Put another way, at a specified frequency, if efficiency, bandwidth, and radiated power are all established as design goals, then equations (4) indicate that an infinite number of trades of capacity and effective height are possible, provided the necessary voltage limit can be met. (Note that if a range of frequencies is to be covered by a certain power and bandwidth capability, then efficiency cannot be arbitrarily imposed.) But a voltage limit may not be arbitrarily acceptable because capacity and conductor dimensions including height are interrelated, so that effective height (capacity centroid) and capacity are not truly independent; moreover, voltage and conductor surface gradient are related in a way similar to capacity through conductor dimensions; finally, the gradient

must be less than a definite upper limit (for dry surfaces -- for wet or dirty, a degradation factor must be included). These so-to-speak coupling relationships are the following:

$$C_o = (2\pi\varepsilon_o \ell)\left\{F\left[\log_e\left(\frac{2h}{a}, s\right)\right]\right\}$$

$$E = \frac{V}{a}\left\{G\left[\log_e\left(\frac{2h}{a}, s\right)\right]\right\}^{-1}$$

$$E \geq E_c = 2.35 \times \left[1 + \frac{0.0322}{\sqrt{Ka}}\right] M\ F\ K \times 10^6$$

in which h is the height over ground of a conductor segment of cross section radius a, s is interconductor spacing in an array of elements at the same potential, V is voltage, E is gradient in rms volts per meter, F and G are the functional relationships appropriate to the conductor geometry at hand, ℓ is the length of a conductor element, K is relative atmospheric density (1.0 is sea level at STP) and M and F are surface and frequency factors. The factor $2.35 \times \sqrt{2}$ is recognized as the breakdown strength of air in kV/mm for plane (uniform field) electrodes at STP, at dc or power line crest voltage. At the locations of most of the VLF stations existing today, K can be realistically taken as 0.95. If care is taken to avoid snags and abrasion during manufacture and installation, experimental evidence from the antiquity of power line practice indicates M may be about 0.75; comparisons of corona onset at 60 hertz versus LF seem to show F to be about 0.9. The joint effect is that approximately

$$E_c = 1.6\left[1 + \frac{0.033}{a^{1/2}}\right] \times 10^6 \text{ volts per meter}$$

apart from degradation due to wetness. This last is roughly accounted for by the observation that the maximum field over a hemispherical protuberance on a plane is three times that ambient over the otherwise undisturbed plane, so that a small droplet on a surface of large radius would cause a similar local increase and and thus the gross breakdown gradient would be further reduced by such a factor. In practice, not so conservative a reduction is used, so that instead of 1.6, one typically finds a value of 0.65 to 0.8 in use, this limit to apply to those parts of the antenna conductor surface where charge is most heavily concentrated, namely, the ends. Thus, the <u>average</u> allowable limiting gradient may be about 0.4 kV per millimeter for worst case conditions.

In the course of several designs for high power, a real question has thus arisen whether it is economically feasible to support conductor at the required height, having the necessary surface area with realizable structures, quite apart from the necessity to find insulators with the necessary strength-to-weight ratio and voltage rating. It can be seen, in fact, that if there is no stringent limit imposed on real estate area, it may be cheaper to allow the antenna to spread out for increased capacity to trade for voltage for a given power radiated. On the other hand, if the extent of the site imposes a limit, as was indeed the case for several situations of upgrading existing installations, then a premium is placed on height versus voltage, and in either case one quickly runs into either a structural problem or a voltage rating limit for the insulators (as well, possibly, for the active conductors).

1.3 Performance/Configuration Trades versus System Requirements

Although this report is not intended to relate design trades in any detail, it is worthwhile to put the above remarks in somewhat more concrete terms by mentioning the design goals for the three main VLF/LF systems to which the insulator problem is addressed. These are the Omega Navigation System (low VLF), VLF communications (high VLF), LF communication; Loran C, an LF navigation system, has such moderate performance goals that insulators are an unproblem, and so is not dealt with here.

For Omega, in the frequency range 10 kHz to 14 kHz,

$$P_r \geq 10 \text{ kW}$$

$$B_{as} \geq 10 \text{ Hz at } 10 \text{ kHz}$$

$$\eta_{as} \geq 0.07, \quad P_{as} \leq 150 \text{ kW}$$

For VLF communications, the present goals are somewhat different from those of 20 years ago when the last generation of upgrading began. These were formerly

$$P_r \geq 500 \text{ or } 1000 \text{ kW}$$

$$B_{as} \geq 50 \text{ Hz at } 15 \text{ kHz}$$

$$\eta_{as} \geq 0.5, \quad P_{as} = 1000 \text{ kW or } 2000 \text{ kW in modules of } 500 \text{ kW}$$

Recent improvements in modem have led to increasing attention to frequencies higher than 18 kHz and bandwidths of 200 Hz or more, with the same limits as before on power and voltage.

For LF communications,

$$P_r \geq 20 \text{ kW}$$

$$B_{as} \geq 200 \text{ Hz usually at } f \geq 50 \text{ kHz}$$

$$\eta_{as} \geq 0.4, \quad P_{as} \leq 50 \text{ kW}$$

Cost trading of structures for the two VLF cases have led to effective heights grouped rather closely around 185 meters in all cases but one or two under a roughly 200 kV voltage limit; the low power and efficiency for the Omega system allows the site to be rather less than a square mile and a moderate capacity to be 0.03 ufd; structures are lighter because less conductor surface must be held aloft, in comparison with the VLF communication stations which, with similar but slightly larger site limits, must be in excess of 0.045 ufd up to over 0.14 ufd to hold the voltage limit. Even then they cannot safely handle the maximum desired input power below a frequency somewhere in the middle of the band, whereas the Omega system antennas are all transmitter limited (i.e., voltage is less than the maximum) at all frequencies above that at the bottom of the band. At LF, the siting requirements are much less, and the voltages to handle can be as low as 50 kV; in some cases 100 kV was made a requirement.

Although the individual site environmental conditions must be properly accounted for in making structural evaluations of candidate insulators, it can be seen that for Omega, contrasted with communications, for equal site environmental factors, the structural requirements are less stringent than for the communication installation. Moreover, the differences in modem between the two systems is highly significant in relieving electrical stress requirements for the Omega system in comparison with the communications system. The Omega system uses basically an ICW modem which requires continuous transmission of a carrier at each of five frequencies for slightly less than one second's duration each over a ten second epoch with a 100 millisecond period of interruption between each keyed segment. Thus the insulator withstand requirement is for about one second in ten for the most extreme condition of 10 kW radiated at the lowest frequency for which the highest voltage requirement is attained. For the communication system, on the other hand, the use of the VERDIN MSK modem means that for any transmission frequency less than that at which the antenna system becomes transmitter limited, the insulators are operated at the maximum rated value 100% of the time, much as are power line insulators. For the same nominal operating voltage, an essentially infinite withstand in comparison with a 1 second withstand implies insulator rating selection that is quite different and leads to insulator dimensions and hardware arrangements that are much larger and more sophisticated than in the Omega case.

A somewhat peripheral requirement has been imposed by the Navy in the last 25 years in the form of a "failsafe" feature, which means that

the guying system must be stressed in a way to almost guarantee no mechanical failure under any conceivable environmental condition. This becomes an unproblem for guyed grounded towers, but for base-insulated monopoles, where the structural guys must also take the electrical stress, it implies that the porcelain insulating elements must be enclosed by interlinked metallic loops (either castings or cables) in such a way that in the event of the destruction of the insulating element, the metal members cannot separate. The porcelain is thus worked in compression (a favorable condition) between mountings that can come together if the porcelain crushes. These must be designed to be so rigid in order to avoid local overstress in the porcelain that the metal components become very massive and the strength to dead-weight ratio becomes comparable to what would be obtained if the porcelain element were worked in tension and sized to give an adequate safety factor (even though not in principle failsafe). The sheer mass of metal that must be suspended in the insulator "point loads" in the guy system becomes highly significant in the stressing of the tower that must hold them up. The implications as to cost of the installation is a strong motivation to investigate availability and properties of insulating materials that offer a very high strength to weight ratio when worked in tension in comparison with what is know about porcelain. Were sufficiently high strengths attainable, the so-called "failsafe" feature could be done away with and a further simplification and cost savings effected.

2.0 INSULATOR SPECIFICATION BASIS

The writing of a procurement specification is simply producing a verbal description of what is desired in terms of structural performance and safety factors, hopefully maximum dead weight and electrical characteristics. The outcomes for power line applications are rather different from those of the radio frequency installations, mainly because of strength to weight aspects, accessibility for maintenance and repair, and frequency of operation. To provide some predictibility as to behavior of members of a production type, the electrical industry has over the years developed standard procedures for establishing electrical parameters and comparisons. These are set forth in such documents as ANSI C29.1, C68.1, and the NEMA 107 for noise interference generation. The characteristics tested are actual disruptive flashover for various standardized environmental conditions, the statistics of interruption frequency as flashover is approached from below, and corona or partial discharge inception levels. These procedures give excellent bases for comparing performance among individual size variants in a given type or genre, and even between similar sized members of somewhat different but resemblant types, but they do not address the definition of performance of a radically new type except in comparison with old, and even then only under the highly artificial conditions of the environment called out in the procedures, especially for contamination of various sorts. These limitations are called out in the text of the standard documents themselves. Thus, as guides for development of new types, they may be regarded as adequate but not as definitives for performance. Moreover, as implied

above, in widely differing frequency regimes, the same unit may behave quite differently, and this aspect is not addressed in the procedures. Lack of appreciation of the deficiencies in these standard tests turned out to be crucial in leading to the failures experienced in radio frequency applications.

2.1 Power Line Aspects

At voltages comparable to those used in the VLF/LF radio systems, the power line industry makes a great deal of what is called leakage path on the insulator surface and ratings for withstand which are expressed in terms of Basic Impulse Insulation Level (BIL) and not necessarily on long-term steady state withstand. Assuming no significant energy loss in incipient corona discharges, it turns out that most of the power line losses in the suspension systems are due to leakage resistance, that is, in E^2/R losses on the surfaces mainly from dirt and moisture. Very little energy is dissipated in dielectric type losses because the porcelain itself has a very small loss tangent and because (mainly) the reactance of the self-capacity of the insulator is so high at power line frequencies that capacitive currents (total displacement flux) may be a couple or orders of magnitude or more smaller than the leakage (resistive) currents, even though the gross insulator resistance may be of the order of 100 Megohms.

To maximize the leakage path in a given length of insulator body and to make it relatively immune to large variations due to wetting and contamination, so-called anti-fog type "petticoats" are incorporated on the surface. These, in themselves, have little effect on the breakdown characteristics of the unit under dry conditions, but during heavy rain, they serve to break up connected streams of water tending to short out the unit, by a combination of drip formation and by electrostatic repulsion of water from the surface; under these conditions, they raise markedly the break down levels from those experienced from similar units without the petticoats.

In low and moderate voltage systems, the insulators, when sized to produce acceptable conduction energy losses, turn out to be so grossly oversized for voltage that attainment of withstand is almost automatic.

In very high voltaged systems, on the other hand, the cascading of short elements into very long assemblies to reach desired leakage magnitudes does not necessarily give corresponding increase in withstand, flashover or corona immunity ratings or, more particularly, in freedom from arcing due to switching surges or induced impulse from lightning strokes (either direct or neighboring). The impulse behavior attainment becomes controlling and, when reached, involves implicit design to control fields associated with capacitive distributions in such a way that the long-term withstands are almost automatically attained and leakage resistance almost surely is. This is because the test for pass is a statistical freedom from arcing in response to a standard impulse of specified rise and decay times (1.5μs up, 40μs down) such that the unit is being tested by energy having very significant high frequency distribution.

2.2 Radio Frequency Devices

At VLF and above, the reactance of the self capacity of most insulators becomes low by comparison with the shunt resistance whether the latter is a surface effect or an equivalent expression of normalized dielectric loss. The performance of the insulators made of electrical porcelain, even when contaminated to some degree, is thus largely controlled by field distributions around the end cap hardware and in and along the porcelain body surface. Attention is largely given to testing for pass for long-term withstand because that is the mode of use in present day radiation systems; and impulse behavior is of relatively little importance because special protective devices in the form of gaps or lightning arrestors are used to protect the insulator at levels well below those at which the insulators would be expected to fail.

Beyond this important difference in electrical behavior, the relative inaccessibility for maintenance and repair of the units in an antenna compared to the case in a power line, and the requirement, for the sake of lightness, to work the material at much higher unit stresses (in power lines, insulators are largely required only to support dead weight loads of wire and simple small substation frames), leads to configurations that are far removed from the basic simple shapes that are addressed in the performance comparisons described in the standard test procedures. Thus, these procedures may not be relevant and since in antenna applications what is desired is failure-free operation in certain specific environmental conditions, the acceptance tests using the highly artificial deposition of water and contaminents described in the ANSI documents, may not be of significance.

This aspect was apparently realized by the early workers in high power communication installation design, but was, to a degree, neglected later on because of long-term use of the same standard insulator designs through the erection of Jim Creek in the late 1940's. When procurement of insulators for the third generation of stations starting in the mid-1950's was undertaken, it appears that power line practice was assumed to be relevant for acceptance testing and this approach persisted until lated in the 1960's and early 1970's.

It is a matter of record that in the original procurement specifications published to contractors for the insulators for NAA (Cutler) NWC (Australia) NPM (Lualualei), the various LF installations, both Navy and Air Force, and for the Omega navigation stations (the original four, at any rate), the Navy and its consultants made no mention of acceptance procedures addressing specifically the radio frequency regime. The whole thing was based on power line practice. An example of such a specification is incorporated here in Appendix A.

3.0 BRIEF HISTORY OF VLF INSULATOR FAILURES

Because of siting limitations and because of a supposed advantage in cost versus performance in emphasizing electrical height, decisions were made in the mid-1960's after NWC was under construction to use base insulated towers at NSS and NPM and in some of the Omega stations. These towers turned out to be so massive and imposed such large dynamic loads on support systems that providing adequate structural strength in the insulators became a major investigative problem for which there was no historical precedent. For lack of any better approach, within funding limits imposed on the new construction, it was apparently determined that careful enlargement of existing designs to meet the new stressing would serve adequately. The situation was a direct outcome of the imposition to design to cost.

3.1 Annapolis

The upgraded NSS radiator consists of a base insulated center tower 1200 feet high, surrounded by six grounded guyed towers of lesser height between which is strung a cable topload roughly hexagonal in plan similar to the German Goliath. This is connected to a "comet's tail" remnant of the old antenna, the triatic topload mounted on the three remaining free-standing 600 foot towers and one pair of the new guyed towers. The base insulator assembly (BIA) was a three-deck stack of nine Lapp hollow porcelain cones, three to a deck, with a total height for the BIA of roughly 120 inches. With 21 inches of exposed porcelain surface per cone, there was a leak path of 63 inches, and the metal rain shields gave an air arc path of about 100 inches. The assembly was protected originally in its entirety by a single gap consisting of metal spheres mounted on the ends of adjustable metal arms. Figure 1 is an outline sketch of the unit.

During high power testing for acceptance of the completed radiation system in late 1971, severe arcing at the base insulator interrupted the program. Inspection of the BIA revealed a vertical crack from top to bottom of one of the cones in the top tier. Subsequent internal examination indicated that the immediate cause of the fracture was thermal shock from an internal arc. The probable reason for such a failure has never been definitely settled, but it was concluded that there may have been moisture on the internal surfaces which had had no chance to bake out after an extended period of idleness following erection.

3.2 Lualualei

Lualualei (NPM) was a completely new installation at which two 1500-foot towers were constructed on the locations of two of the old 600-foot free-standing grounded towers. The new structures were guyed and base insulated, each supporting its own unbrella cable top load, and each was supported by a BIA identical to that at Annapolis. After acceptance, the station reported trouble remaining on full power operation during light rain, but there were other mysterious occurrences not associated with inclement weather. An extensive series of tests during early 1972 failed to produce significant improvement in what appeared to be deficiency in protective gap performance, but a revised system was installed into which was later incorporated a sensing device that gave a carrier cut-off (CCO) capability to the system to anticipate incipient arcs and to eliminate traumatic interruption of the transmitter. Some controversy between various agencies in the Navy and the manufacturer developed over the probable causes of what at the time were assumed to be overvoltages, but these were subsequently proved to be nonexistant.

Meantime, a different BIA design by Continental Electronics Manufacturing Company, using solid petticoated station posts provided by Cerelap in two decks of eight each, had been accepted for use in the Omega 1200-foot base insulated towers. Based on their similarity to the Annapolis center tower, it was determined to test it for possible use there; but, since availability of assembly was some time away, a parallel effort was mounted to devise a way of increasing protection of the Lapp BIA's at Lualualei in

order to avoid future tower jacking there. At Annapolis this had already been done to permit removal of the faulty BIA. A new series of NPM tests, commenced in part in late May of 1972 and continuing through October of that year, gave incontrovertable evidence that, not only was a single gap inadequate, but the BIA itself was electrically deficient in respect to its procurement specification. The problems were twofold: the smooth porcelain surfaces permitted formation of connected sheets of corona in impinging rain and subsequent arcing and shorting of individual units, and the rain shield hardware itself was subject to premature arc-over. These problems were apart from the protective gap difficulties. The NPM tests were terminated when an extremely hot region was discovered on Cone No. 2 one of the bottom-most elements in the east tower BIA, and warm spots were found on one of the center units at west tower. Subsequent investigations indicated that a hidden exfoliation crack extended for about 120^{o} around the lower portion of the hot unit, and that there may have been voids, euphemistically referred to as "inhomogeneities" in the questionable west unit. As for Annapolis, the cause was never really determined, but it appeared likely that this fracture may have been induced by too-rapid unloading during structural acceptance testing, not by any electrical failure.

3.3 Omega

Before the first base insulated tower installation for the Omega system was ever completed, much less tested, there was considerable controversy between the Navy, its architect-engineer and his consultant, Westinghouse, on the one hand, and the construction contractor, Woerfel Corporation, on the other hand. The controversy concerned the acceptability of the guy strain insulators in terms of meeting electrical specifications which were still, at this time, of a 60 hertz basis. Previously, there had been questions about the dimensioning of the base insulator and its protective gap, but these did not become paramount until later. The best way to report the history of the guy controversy is to include Appendix B, which should have given advance warning of what was to come to all concerned. This, very briefly, was the catastrophic failure of the center post of the pentapost units. Figure 2 is a sketch of the BIA and Figure 3 is a typical pentapost. It was a derivative of the original quadrapost design which was to have been used throughout, until the Naval Facilities Engineering Command determined that there was some question about the mechanical stability of the assembly under high structural loads; thus the center post was added for stability. It proved to be badly overstressed electrically, and actually degraded the electrical performance of the insulator.

Although an existing design from Lapp was available for the main top-load guy insulation, the same supplier of the structural guy insulators produced a very light high strength unit consisting of a number of fiberglass rods encased in a porcelain jacket for anti-corona and environmental protection and the whole filled with transformer oil (a modification after an earlier version of the units, filled with a semi-solid called "biwax"

failed catastrophically due to internal burning in a void in the dielectric material). Since even the oil-filled modification was under suspicion, ultimately the Lapp cascaded "double triple" station post unit was resorted to as a replacement.

The BIA became a problem in that the air gap between the lower edge of the rain shield and ground was so small that the unit never met specification at VLF even though a pass was declared for straight ANSI 60 hertz tests. One of the main deficiencies in these standards became evident which was the highly artificial nature of the wet tests. Aside from the insulator per se, there was difficulty again, as for the communication stations, with the single electrode gap protective device, which in this case, consists of a single "L" configured arm with a large sphere working against the edge of the rain shield.

3.4 Sixty Hertz Power Electrical Isolation Devices

Since warning lights are an FAA requirement on high towers, 60 hertz power must be brought across the VLF insulating gap in a base insulated tower. There are various ways to do this: by transformer, by placing the power conductors inside a tubular rf connection, and by variously configured rotating units incorporating an insulating shaft connection. The latter scheme was accepted for both the communication stations and the Omega system, mainly because there was no precedent for accomplishing the objective across so high an rf voltage. Readily available existing isolation transformers had been used up to about 100 kV. The rotating units supplied by Lapp consisted of a generator surmounting two stacked hollow insulators under a dunce-cap-shaped rain shield, mounted on a steel table under which was placed a drive motor connected to the generator by a porcelain shaft running up through the outer petticoat insulators through three bearings. The whole device was filled with sulphur hexaflouride.

It is out of place here to describe the many mechanical problems, although some of those problems impacted on the electrical performance. The units passed the ANSI C29 testing procedures but failed to live up to expectations at rf. On more than one occasion, one of them arced internally during rf testing, and the extended withstand was under specification. This was shown to be a combination of unbalanced distribution of potential between the insulating sections and of too small a radius of curvature at the edge

of the dunce cap. There was, moreover, no protective gap system since it was assumed orginally that the device placed for the BIA would serve to protect the entire system.

Prior to the arrival on-site of production rotating isolation units (I.U.) a platform-mounted diesel engine-powered generator placed on four station post insulators of four sections each, the entire unit being about 12-feet off the ground, with fuel fed through a hollow tube insulator, was used as a temporary expedient. Resultant difficulties in operations were not in meeting rf requirements, so these will not be discussed.

After repeated experience with unreliability in rotating units, a procurement was arranged with the successor to the A.O. Austin Company which had supplied lower voltage insolation transformers in the past for construction of replacement devices at the five 250 kV insulated towers in the communication and navigation systems. A development program was required to solve moderate deficiencies in the protective gaps, but other than one internal rf failure, there were no outstanding acceptance problems.

4.0 EARLY INVESTIGATIONS FOR FIXES

Up to the middle of 1972, most of the emphasis on attempted remedies was on investigation of the properties of the protective gaps. At the time, a lot of this effort was directed at providing single, more or less uniform field-type gaps, which subsequent experience showed was not the direction in which to go. The deficiencies in the insulators themselves were not so evident, partly because no one could believe that devices which had passed the ANSI test procedures should be expected to fail. Additionally, it was felt that if there were an over-voltage problem, it had to come from real, unsuspected induced resonances or harmonic response to undesired spurious components in the transmitters. Many of the early tests are reported in references (1) through (6). In addition, Appendix C shows two such test plans, the second of which was generated by the author at NELC in May of 1972 in response to a request by NAVELEX following the first so-called "Ad-hoc VLF Committee Meeting" at which the problems and their attempted (failed) solutions were thoroughly discussed by key representatives of ELEX, NAVFAC, CNO, COMNAVTELCOM, SUBPAC, Lapp, Holmes & Narver, NELC, NBS, NRL, Westinghouse, and the two communications stations.

The motivation and objectives of the NELC tests at Lualualei are evident from the text of the plan. In the event, it was found that the spurious induced and resonant responses were not present and that the insulator itself, as well as the gap, was deficient in sometimes spectacular ways under spray wet condition. These tests took place in the period of

May 22 through May 29, 1972 and proved to be the beginning of the NELC Insulator Test Directorship that extended through the next four years during the entire VLF antenna upgrade effort. It was from this time forward that the thrust developed to qualify insulating devices at rf in realistic test conditions and to incorporate such requirements into specifications, in addition to any prior qualification that might be necessary as a preliminary at 60 hertz. It became evident that the properties of protective devices were not so well known as believed and so a closely associated effort was mounted as part of the overall program to arrive at gap types and arrays that would perform this function as desired.

The first NPM tests were reported and thoroughly discussed at the second Ad-hoc meeting in early June, 1972. It was at this meeting that NELC was commissioned to set up the first high voltage test facility for an Research and Development effort that could be carried on without impacting the availability of the VLF station for normal use. The test facility was set up adjacent to the helix house under the three-tower LF antenna at NRTF Chollas Heights, San Diego (previously used as a development bed for the Omega Navigation System by NELC). The special developmental VLF transmitter for Omega was used as the power source and the helix and antenna itself were used as the high voltage-tuned circuit to provide the test energy at 9.8 kHz. The available voltage was limited by the ratings of the components to about 140 kV rms and power was 60 kW gross.

5.0 TEST PROGRAM CHRONOLOGY

Tables 1 and 2 show the complete history of the test sequence in chronological order as nearly as can be reconstructed at the present time, nearly five years later. Table 3 shows the sequence and dates of travel by this author in relation to that test history. The test program was generally started with efforts to confirm the original Lualualei test results, to look at some aspects of the Lapp BIA failures in enough detail to arrive at fixes, if possible, and to quantify the rf behavior of the candidate base insulator (used in the Omega system and manufactured by Continental Electronics) as a replacement for the Lapp unit at Annapolis. It was quickly realized that a test bed with double or more the voltage capacity of the Chollas Heights antenna system would be needed to test an entire assembly, although many results for single insulator units or deck assemblies within a complete BIA could be obtained with the 140 kV limit. This led to an attempted on-site fix at operating voltages at Lualualei which, in turn, fortuitously permitted early discovery of the cracked porcelain there. On the other hand, it led to the uncovering of a previously unsuspected limit on certain high voltage capacitors, their design troubles, and the properties of liquid dielectrics. This account will not deal with the capacitor investigation.

Throughout the program and its modifications, the major NELC Test Director sponsor was PME 117 within NAVELEX. This organization systemized the exchange of information between the investigators and other interested agencies in the Navy and among the contractors, as well as supervised the direction of the sequence as it unfolded. This was done

in part by a committee whose membership was drawn from the above listed organizations and known initially in the program as the Ad-hoc Committee, and later on as the VLF Steering Council.

6.0 HISTORICAL ACCOUNT OF THE TESTS

In the following discussion, the actual chronological order is not followed, but the discussion describes groups of tests somewhat by insulator type. This seems desirable so that the account of developments of the hardware for a given type will not be fragmented. The individual steps in a development sequence sometimes were separated in time over several months, and formed portions of separate occasions of operations at the NELC Lualualei High Voltage Test Facility (NELC/LLL HV Test Fac).

6.1 First Lualualei and Chollas Heights Tests

6.1.1 Lualualei

After assembling equipment and carrying out calibrations of base characteristics at the station so that actual voltages were known in terms of feed point current, the tests addressed the behavior of the BIA as a whole under dry and spray wet conditions in order to determine if Dry Flashover, Wet Flashover, Dry Corona Inception, Wet Corona Inception (DFO, WFO, DCI, WCI) and excessive heating took place in full power operation. In view of the pass under 60 hertz tests, such events were not expected. Additionally, the tier-to-tier distribution of voltage was measured (grading) and an attempt was made to calibrate the protective gap, which by this time had taken the appearance of a cylindrical can atop a slightly smaller diameter post, place adjacent to, and at the same level as, the edge of the topmost rainshield. A detailed discussion of the results, quantitatively, is beyond the scopy of this report and will be dealt with in a follow-on report. Qualitatively, it was found that the grading was unequal, with about half the total base voltage appearing on the top tier; according to the manufacturer, this was deliberate so as to apply the most voltage to the deck which had the greatest rain protection. Each individual tier was supposed to withstand, by itself, almost the full operative base voltage with the others shorted out, and, while under dry conditions this was almost true, it turned out to be grossly untrue when wet conditions prevailed. The gap could be successfully calibrated and showed dependable operation up to two-thirds of the normal operating base voltage. Beyond this level, its

behavior became increasingly erratic until, at full base voltage, it offered almost no dependable protection at all. Also, the arcover voltages were heavily dependent on local environmental conditions, including the presence or absence of gnats or flies.

When dry tests were conducted in the absence of the gap, the BIA appeared to operate successfully at full voltage. However, when wet, the events were spectacular. There was much evident corona on the surfaces of the porcelain and a strong tendency for initial formation to occur at the edges of the metal caps and base rings. The actual arcing took place from rain-shield segment to rain-shield segment and the arc location was not stable, apparently sometimes taking place along the surface of the porcelain. Arcs originating from the top rain shield to protective device when present, could and did migrate to intra-tier locations.

An effort to improve the grading was undertaken through the use of sections of six-inch stove pipe assembled as a grading ring extension of the rain shield. This is shown in Figure 4.

6.1.2 Chollas Heights

Since NPM was still considered an operational installation, it was determined that more detailed and extended tests could be performed at leisure at the Chollas location, although full base voltage could not be developed. Accordingly, a concrete pad was poured south of the helix house, about 30 x 40 feet in dimension with a ramp so that fork lifts

could be driven thereupon for handling components. A complete example of the Lapp BIA was shipped to San Diego incorporating some of the elements that had been in the Annapolis BIA. This was set up on the test pad as a complete BIA during the latter part of the tests. The first sequence addressed studying the properties of a single tier of three Lapp cones. This tier was subjected to DFO, WFO, DCI, DWS, and WWS tests. The latter two are so-called withstand which are statistical determinations of the length of time between successive arcovers as flashover is very slowly and repeatedly approached from below as a function of applied voltage. In industry, various ratings are 10 second, 30 second, one minute, and ten minute withstand. Of interest for high voltage rf installations is a so-called long-term withstand of perhaps several hours duration since required station reliability implies a total of a very few minutes non-operation per 24 hours. The single deck was mounted on a steel table in a geometry identical to that of the BIA and with a steel plate overhead that could be used to mount a rain shield. The supporting table had holes in it corresponding to the open base rings of the insulators in order to render visible any internal events as flashover was approached.

The very first significant observation made while assembling the single deck for test was that the insulators arrived onsite in open crates with no protective wrapping and that they were treated inside with a roughly one-sixteenth-inch thick film of silicon grease which was heavily contaminated with dust and dirt particles. According to the manufacturer, the (clean) grease was used as a retardent to WWS degradation due to surface

contamination as the silicone grease acts to encapsulate the particles and retard the appearance of connected conductive paths. This practice is followed by some power companies in situations of heavy atmospheric contamination to reduce the necessity for frequent power line cleaning. Therefore, the question arose immediately concerning the lack of protection for the grease film from contamination during shipping, and, as an outcome, it appeared that a possiblity existed that the BIA elements were in a similar condition when assembled into the Annapolis installation. To produce test results giving the most favorable outcome for the insulators, it was decided not to proceed with them in their as-supplied condition, but to clean them up. The grease was removed with solvent and detergent, which proved to be a difficult and offensive procedure and the insulators were then subjected to the DFO procedures, DCI, DWS, and then WFO, WCI, and WWS in that order when assembled into the one-tier deck on the table. The wet procedures were repeated for both external and internal application of water spray from which it was found that an internal flashover could be induced at about 125 kV rms after a corona inception at 90 kV. In view of the grading as built and the expected 200 kV operating voltage, the implications of these results in view of the contaminated interior conditions of the BIA were obvious. It was also evident that inspection of the interior of the LLL BIA was of some importance, as well as attempts to equalize the grading in order to reduce the load on the top tier to a value below that for corona inception.

A second very significant series of tests was the WFO and WCI externally. Dry conditions produced no test, as the DFO and DWS of the individual units were beyond the ability of the facility to produce arc-over voltages. Corona inception was found, not surprisingly, to be at the interface between the porcelain and the end hardware which was configured to produce high local concentrations of field. A rough calculation showed that the actual local field could be four or five times higher thatn the field along the surface midway between the end hardware, so that inception levels wet could be expected at gross voltages of around 80 kV or less. Withstand (long-term) tests were conducted up to around 100 kV. Therefore, in the as-built BIA, the top tier under spray wet conditions appeared to be a marginal operation at best. This all was quite apart from the problems about the protective gap device.

When WFO occurred, it usually produced an arc directly between the base ring and the top end cap along the porcelain surface with attendant local thermal shock, especially near the terminal points of the arc. In one of the units, repeated arcing eventually produced exfoliation failure of the porcelain surface over an area of about four square inches, although no propagating crack appeared in the porcelain body.

The evident conclusion from these early tests was that the local gradient along the insulator should somehow be equalized and the first attempt to do this was to mount toroids immediately adjacent to the edges of the end hardware next to the porcelain. By using a pair of such rings,

one of larger diameter and mounted outboard of the other, an approximation of a Rogowski surface of revolution was produced that showed promise of accomplishing the desired result. Under test, the experimental modification showed mainly that the resulting arc path was removed from the insulator surface, but the gross withstand voltage was not improved much; mainly, it appeared, because of surface roughness of the jointed tubing used and because the approximation to the Rogowski surface was not very good. It became known that Dr. Richards of Science Applications, Inc. had developed a computer program from which the fields next to an insulator displaying rotational symmetry could be calculated accurately and such modifications as Rogowski rings could be configured to a high degree of precision. Subsequently, such a contract was let and tests of these devices were conducted at Lualualei after the Chollas sequence ended. Later, a similar computer program was developed at CEL.

The formation of corona after inception was looked at carefully before and after application of the rings and the value of equalizing local field distributions was quite evident. In the as-supplied condition, the corona spread in the water drops on the wetted surface progressively in sheets from the high field regions into the lower as the gross voltage was raised. Just under flashover, intense partial arcs, called flares, became noteworthy; these, in themselves, were sufficient to cause significant local heating and danger of thermal shock. In the presence of the field shaping rings, the formation of the corona sheet was much less regular and considerable more randomness was observed so that less constant local heating

took place and there was less likelihood of connected sheets forming at voltages much less than that for actual arcing. In either case, it was observed that the smooth surfaces of the cones made them very susceptible to the formation of sheets of surface corona and subsequent disturbance of transmitter matching conditions, as well as thermal shock, premature arcing of the unit, and upset of assembly voltage distribution.

Because evidence had accumulated in the past that there was some difference between corona inception levels as well as flashover levels for 60 Hertz versus VLF (References 7 and 8), comparisons were run of behavior of standard rod gaps at the two frequencies. The motivation was to see if these differences could be involved in the fact that 60 Hz test pass produced a device that failed to meet specification at VLF. While at Chollas, qualitative differences were observed in the appearance of corona in the gaps at the two frequency regimes, it could not be said that much difference of flashover levels was observed, although dry corona inception levels were quite different.

The first version of a standard gap tested was a rod-rod gap using square cross section stainless steel in a horizontal plane and mounted so that the gap was sufficiently distant from the supports as to be in an essentially undisturbed state. By comparison with sphere gaps, it was determined that the square section rod-rod gaps gave lower level activation but more predictable behavior, that is, less randomness. From this it was concluded that a gap having a highly divergent field should be capable of

being preset dependably to a given level in a more reliable fashion than a sphere gap which has a more uniform field and is more subject to premature firing due to surface irregularities. One such non-uniform field gap was a sphere-to-ring gap arrangement which could be mounted coaxially within the BIA tiers. Since its activation level would probably be less than for the LLL BIA gap, it was decided to arrange the new gap to protect each tier individually. As tested, the device showed promise, but there were difficulties with the execution of the hardware under the time limit of the tests, and there was a fairly obvious disadvantage of the location of the arc path.

Still using the single tier test object, a direct comparison was made with the properties of a deck made up of several Ceralap petticoated units, again both at 60 Hz and at VLF. It was found that the petticoats eliminated the formation of sheets of corona on the surfaces and that the deck with Ceralaps could not be arced under any condition, although the end hardware of flat plate was the same as for the Lapp units and the overall axial dimensions were nearly alike.

The Lapp BIA was finally assembled in its entirety and tested for grading as-built and with an extended rain shield of outside dimensions and location over ground the same as that of the open stovepipe grading ring triod at LLL. This was fitted directly over the original bottom two rain-shield segments, but the top section was removed before the extension was mounted. As by this time some attention was being given officially to the installation of some kind of partial environmental shield, this was modeled

with hardware cloth on timber supports as a sort of fence around the BIA in the presence of the extended top rain shield to determine what the separation would be to avoid seriously disturbing the grading obtained without it. The limits were determined and the dimensions subsequently used in connection with an experimental enclosure later tested at Lualualei. 60 Hz and VLF tests gave similar results for the grading.

Within individual tiers, a final series of experiments showed that the difference between withstand levels for spray wet conditions and for the "drip-dry" situations as specified in the ANSI procedures was substantial. The latter states that the test object shall be sprayed at a specified rate with 45° downward impinging water until all surfaces that are going to be wetted are so, then the water is to be turned off and the unit allowed to stand until water drops remain as they will but there is no further draining from edges. In this condition, the water droplets are merely irregularly located protuberances on the metal hardware and, as such, form a surface having a particular statistical kind of roughness; but wetness is not really a relevant factor in the test, especially of the insulating material holding the hardware apart. The wetting and disturbance of the conductivity and the grading of the insulators and the interaction of these with the dielectric properties of the surrounding moisture and droplet laden air under real conditions of rain are thus never tested. This, rather than differences in frequency of operation, appeared to be the cause of the failures of gaps and hardware in the real installations; the fracture at Annapolis appeared to be a result of an internal arc induced by wetness from

accumulated condensation on a bedly contaminated interior surface, thus something should be done to insure interior dryness by sealing or pressurization rather than by silicone.

The rest of the Chollas conclusions were that the gap systems were insufficiently developed, that the overall grading should be improved, and that the local fields at the hardware surfaces should be reduced by suitably increasing local curvature. Grading was not affected by the presence of the tower on top of the BIA -- Chollas and Lualualei results were the same.

Beyond all this, it seemed certainly true that the value of petticoated porcelain was beyond dispute, although the availability of such at the time of the design was nil from U.S. sources in the structural strength ratings required and under the mechanical load equalization requirements of the Navy.

Another aspect of the Chollas tests should be mentioned. This is that it became evident that the detection of corona onset can depend greatly on the lighting conditions ambient at the time and on the use or not of visual aids such as field glasses. Although detection of rfi hiss on a broadcast receiver placed near a device under test can be used as the onset criterion, it is not obvious that unless some standardization procedure is carried out the results are at all comparable to those of visual detection or from the observation of corona currents embedded in a (filtered) sample of the signal current feeding the device. Also, among several human observers, there is considerable variance in physiological sensitivity to the blue, violet, and near ultraviolet wavelengths in the radiation from the

discharge, so that agreement on onset level is often not obtained. Among observers and between test methods, the variations can exceed 5%, and thus become important in the event of a dispute over a pass. Thus, attention was subsequently given to obtaining more dependable ways to detect onset, and investigation was made of using an ozone detector as well as a modification of a kind of Geiger tube device that is used in high voltage installations for the purpose. The Geiger tube device proved moderately successful if it could be adequately shielded from high local fields such as those in the neighborhood of the device under test, but the ozone detector under field conditions for these experiments was impracticable.

In the ANSI procedures, a requirement exists that water used for wet tests be of a specified conductivity. In MKS units, this turns out to be 5.6 millimhos per meter, considerable less than the conductivity of rain water but several orders of magnitude greater than than of distilled water; compared to ordinary tapwater, which can be up to 100 millimhos per meter, it is a good insulator. Thus, a problem arose about supplying standard water in amounts required to conduct extended spray-wet tests that was more severe than would have been the case if the wet tests had been conducted as drip-dry trials. For Chollas, a batch mixing procedure was used with storage capability of 500 gallons. Later this was inadequate at LLL and a continuous production plant was developed making use of two types of zeolite resins as in water softening systems. The necessity for use of standard water to produce a certifiable test result has never been seriously disputed in the electrical industry, but such few comparison tests as have been reported in

the literature indicate that differences in wet tests due to water conductivity as long as it is of potable quality are quite small; a reported difference of 10% between tap water and distilled water (reduced flashover voltage for tap water) was not realized in subsequent trials at the NELC HV VLF Test FAC. However, to eliminate any doubt about the validity of test results for record, standard water was always used although its provision becamse a matter for significant expense. As an extreme example, a comparison was made between test results using straight distilled water of better than 10^{-5} mhos per meter and seawater, and the reduction was no more than the above mentioned 10%.

The Chollas tests have been related in considerable detail, although in many cases firm quantitative results were not preserved and the limitation on source voltage meant that performance predictions of a complete BIA depended on the validity of assuming that individual tiers could be added by superposition with due regard for grading (which proved to be true to within about 10 or 15%) because complete devices could not be tested. The reason is that the experience constituted a learning experience for VLF versus 60 Hertz tests, for many of the participants, that subsequently was highly significant in directing the course and approach to future tests. In particular, the experimentation on gaps was fragmentary and later was greatly expanded at Lualualei, although never carried out in as systematic a fashion as would have been done if the project could have been performed as pure research. It is significant that all the conclusions from the Chollas tests were substantiated by the later ones.

6.2 Second Lualualei Test Series

Several parallel efforts were carried on during the second series of Lualualei tests in August 1972. These were mainly contractor jobs with NELC in the position of government inspector. The electronic part of the Architect-Engineer design team performed a two-fold task of: (1) repeating the NELC work of May and July 1972 to confirm that the conclusions about grading, benefit of petticoats, corona inception levels, DFO and WFO voltages, and absence of induced resonant overvoltages all were indeed valid and (2) performing initial inplace testing of a carrier cut-off device in the presence of several different kinds of protective gap systems:

a. That supplied by Westinghouse earlier in the year as a replacement for the original gap
b. The tier-by-tier ball-ring gap of NELC design
c. A sphere to rainshield tier-by-tier design by Westinghouse which was an improvement on the NELC concept in that it removed the arc path to a safer location with respect to the insulators.

These measurements were all performed, both with the original Lapp rain shield, and with the "production" version of the NELC designed extended top rain-shield element. Some were also repeated again with the SAI version of the NELC field-controlling ring collars around the end cap hardware in place. With additionally some cap-nuts installed to hide the sharp edged end threads of some of the insulator element mounting bolts, the entire BIA showed some improvement but in

subsequent operation still did not reduce interruption frequency to a satisfactory level during inclement weather.

The second major effort was by the supplier of the insulator assembly to provide access to the interior through holes drilled in the end hardware to permit visual inspection of the surfaces and to enable a manifold tubing system to be connected by which to pressurize the hollow cones with dry high dielectric strength gas. Using a boroscope, pictures were taken to confirm the visual findings of, in some cases, heavy dust and grout particulate contamination of the silicone treated surfaces, as well as the effects of condensation which had entered in an as-yet undetermined manner. It appeared that the potentially dangerous condition that may have led to failure at Annapolis existed also at Lualualei. While no cleanup of the inside walls appeared practicable, it was decided to proceed with the pressurization; these efforts quickly showed that no such outcome was possible because the grout joints in the insulators themselves were not, and could not be made, gas tight, although a lot of effort was carried on to accomplish this. Not only was gas consumption unacceptably high but under spray wet conditions, SF_6 in the presence of ionization from corona, proved to be dangerously susceptible to dissociation and reactive with the water to produce, among other things, hydrogen flouride in a spectacularly high-temperature flaming reaction that etched the porcelain glaze, in one case, deeply into the unglazed body. During the event, the spectators feared for the structural integrity of the insulator from thermal shock; the result was to abandon

further attempts to seal the insulators. Later on, the joints between the steel base rings and the mounting plates were also shown to be leaky, even to the presence of water. The test sequence is included here as Appendix D, taken from NELC report 1300 - 543 of 16 October 1972.

6.3 Third Lualualei Series: The "Glass Brick Wall"

Since up to this time it appeared that the Lapp BIA was satisfactory in all respects, although it did not actually meet electrical specifications, if it could be kept dry, attention was given to providing some kind of constantly favorable environment. A scheme for an air curtain similar to that employed at the entry of some public or commercial buildings was considered but rejected because of the sheer volume of warm air and the energy source required to drive it. A tight enclosure constructed of electrical porcelain sections supporting a weatherproof rain shield-like extension was impractical because of the cost to design, the delay to produce, the necessary petticoated modular "bricks," and the questions about the maintenance of cleanliness in the unavoidable vertical joints to prevent the formation of continuous carbonized leakage trails across the outside surface of the enclosure, while still attaining structural stability. It was finally determined that a worthwhile test could be performed on sections of wall assembled in different ways from glass brick, since it was cheap, available, dielectrically satisfactory, and adequate structurally. There was dissent in the prediction of the possible outcome of the tests, but it was felt that the case for ultimately replacing the smooth-surfaced cones in the BIA could be made all the stronger if the results from the enclosure were unfavorable. In the event, although the best possible effort was made to carry out a fair test, various factors indeed proved to overwhelm the concept, chief of which again was the volume of air and the energy requirements for conditioning and moving it through the enclosure

as the only seemingly practical way to avoid the vertical electrical leak paths was to construct the walls of vertical sections of single brick width with vertical open slots between held to a tolerance of about one-sixteenth-inch width.

Based on the information obtained at Chollas Heights about the proximity effects of walls on the grading of the BIA, the dimensions were selected and the design carried out by NELC with the result depicted in Figure 4. The rain shields were made of sheet metal with tubing edges for gradient control and served the triple purpose of acting as petticoats, as rain shields, and as grading rings. They were installed integrally in a thirty degree sector of the horizontal joints of the enclosure test section, while as a control for test purposes they were omitted in an immediately adjacent thirty degree sector. The wall sections themselves were one-foot brick sections, ten-high placed on a 48 inch high concrete block parapet that was made electrically conducting by a cover of hardware cloth; the weatherproof roof of the enclosure was electrically modeled with an assembly of hardware cloth and wires supported on a wood frame which was screened by the metal wires. Further electrical modeling of proximity effects on the grading was done with two additional 60 degree sectors of the base wall and roof (without the dielectric portions) so that, ultimately, tests were conducted on a 180 sector of the proposed enclosure.

With a serious defect not evident until wet tests were made, the wall sections successfully passed all dry electrical flashover,

withstand, and corona inception tests with voltages available at the tower base from full power operation of the transmitter. Grading was not exactly equalized, but the variation from top to bottom, tested by the sphere gap voltmeter technique, was within satisfactory limits, with the worst case individual section carrying about 30% more load than the least. In a final design, this variation could be reduced if it were felt necessary. Under wet conditions, the withstand was satisfactory except that when arcing occurred, the path migrated inward so as to lie against the brick which were highly frangible under local thermal stress. Moreover, the silica sand/casting resin grout mix, used for favorable dielectric characteristics, was flamable. This could probably be remedied in a final installation by use of a highly conducting portland cement mix into which graphite or zinc or molybdenum-sulphide were introduced, but the problem with the glass would still remain even if pyrex could be substituted for the ordinary glass used. The bare wall without rain shields was totally unsatisfactory. As before stated, although electrical porcelain blocks could be used instead of glass, they would not have been available in the time frame required by the Navy for executing the fix. Finally, the structural stressing by application of a large vertical dead weight to preclude fracture in the horizontal grout joints by inward buckling tendency from lateral wind loads, was not really resolved in a satisfactory way.

Other tests carried on in parallel with the wall development were further refinement of the tier-by-tier ball-to-rain-shield protective gap and the development test of a revised base current metering system

similar to that used in the Omega transmitting systems that promised a simpler, less costly and more accurately calibratable (and free from variometer position effects) system.

Although there was increasing agreement among all concerned that rf testing of the Omega type base insulator for possible use at Annapolis would be a requirement for acceptance, the feeling persisted that such tests would be made by use on an ad hoc basis of the Lualualei antenna system and transmitter. The same would be true for a new BIA design which now became increasingly important for eventual installation at NPM. But no feeling of great urgency was present, nor was there a great push for construction of a special rf test facility for this; in view of the availability of Chollas Heights for single deck tests, if, as was assumed, the new BIA would consist of multiple tiers. This approach changed abruptly on the discovery, more or less by accident, of a zone of extremely elevated temperatures around a considerable fraction, circumferentially, of the lower portion of one of the bottom cones in the east tower BIA. This event led to ultrasonic examination by NAVFAC representatives who discovered a "discontinuity" corresponding to the location of the elevated temperature, and determinations by NAVSEACTPAC of the temperature rise using a thermistor; the measurement indicated a rise completely out of specification and one which seemed to attain no upper limit. Externally there was no evidence of cracks, so it was thought that there might be something visible inside and therefore inspections by boroscope through the bottom base plate hole under full power voltage

conditions was carried out by NELC. This inspection revealed nothing. The crack, if such it was, must therefore be entirely contained within the body of the porcelain and, since repeated and continued thermal stress from whatever discharge phenomenon was taking place within it might lead to further propagation of the crack and eventual catastrophic failure, the decision was made against further use of NPM operationally until a permanent fix was in view consisting of a replacement BIA. In the meantime, the broadcast coverage area of NPM in the Pacific would be filled in as best might be by continued operational use of NPG/NLK Jim Creek beyond its planned date of retirement to caretaker status. Increased sense of urgency was thus injected into what, up to the end of October 1972, had been a, more or less, business-as-usual approach, and the first order of business was the construction of a high voltage source giving the capability of acceptance testing up to about 300 kV. The assumption of the availability of a "quick fix", so evident in the discussions in the Ad Hoc Committee meetings as recorded in the minutes, was dropped, and serious consideration was given to the writing of a new specification incorporating requirements for high voltage tests at rf.

The general flavor of the approach up to the end of October 1972 is contained in the Ad Hoc Committee meeting minutes of 15 June (9). It is tempting to include this as an appendix, but this would render all the thicker what will turn out to be, at best, an already unwieldy document. In any case, after late 1972, it began to be realized that the Navy would have to provide whatever rf testing capability was going to exist for proving satisfaction of the new specifications, and that there would be, in all probability, no quick fix at least for Lualualei.

7.0 HIGH VOLTAGE TEST FACILITIES

There are numerous high voltage laboratories in the United States for special purposes, but they almost exclusively are of three kinds: continuous application of power line frequencies, generated by large autotransformers such as those built by the Swiss firm Haefley; impulse testers, such as those employed by commercial laboratories in the form of Marx generators to supply the more or less standard lightning pulse; and the very high voltage, high impedance dc generators, such as the Van deGraff machines and linear particle accelerators used for studying atomic and nuclear reactions. As subsequent interviewing of 38 commercial power frequency labs showed, there was nowhere in existence an rf facility of the desired capability, and almost no one showed interest in carrying out the design of such.

Urgency and cost indicated that the construction of a facility for Navy insulator testing would have to be an in-house effort and, accordingly, the task was given to NELC. In the approach to the design, the historical precedent of a high voltage high Q tuned circuit was used.

7.1 Lualualei Transmitter Capacitor Moderate Voltage Facility

The final power amplifier tuning capacitors in the FRT-64 have a manufacturer's identification plate which contains, among other things, a rating of 60 kV in some instances and 50 kV in others. A conversation with the manufacturer revealed that these were intended as a conservative peak rating based on hipotting tests in the plant. A stack of six in cascade would thus perhaps permit attaining 240 kV rms for insulator tests, with an implied peak of 330 kV. Calculation of the capacity indicated that considerable flexibility for tuning with the existing helix house components for almost any VLF frequency was possible. Accordingly, in November, design was started of a concrete pad to be placed west of the helix house. A light aluminum downlead guyed to the face of the helix house and supported by an auxiliary insulator mounted at the edge of the roof and connected to the bushing at the top and resting on a structural bracket atop the topmost capacitor was installed after six capacitors were stripped out of one of the power amplifiers and placed in pairs on the pad. Each successive pair was mounted physically higher to correspond to the voltage applied to the supporting insulators. These latter were obtained by demounting the platform-mounted engine-generator tower lighting sets and tower lighting was not disturbed since they were grounded by the boarding ladders and light fed from "shore" power. The entire work of design and installation was completed with the considerable aid of station forces by early January 1973. Conceptual sketches are shown in Figures 5 and 6.

Although calculation of the breakdown voltage for the plate spacing and oil dielectric gave about 76 kV peak, it was considered prudent before applying full voltage to the stack to place a seventh capacitor in parallel as a sacrificial test object to see what the actual breakdown voltage really was. Using the undisturbed PA as the power source, voltage was slowly increased while current was monitored carefully both at the transmitter through the newly installed base current metering system and by an oscilloscope presentation in the little shielded observation hut that had been used before at tower base tests. This hut was equipped with a capacitive divider local field sensing device for sampling voltage on the test piece as well.

As the voltage approached 18 kV rms, the current was observed to commence a rapid rise not in proportion. Before the circuit could be deactivated, the oscilloscope presentation showed a rapid random variation of amplitude which was accompanied by a strange noise from within the test capacitor similar to muffled flatulence. Several repeats showed a successive decline in the voltage for initiation, and when this had fallen to 11 kV, testing was halted, the capacitor was disassembled, and the plates and separators showed clear indications of internal arcing.

Obviously, this low failure voltage caused considerable consternation, not only because of the implications for the presumed high voltage facility, but also because of the expected steady state voltages to be applied to capacitors of this same design in the FRT-87 at Annapolis. At the older stations, such as Cutler, Australia, Panama, and Lualualei, the PA tank voltages had never placed more thatn about 10 kV on the capacitors, and no failures from this cause were ever recorded.

To eliminate the possibility of the early failure being a fluke, a second capacitor was similarly tested with similar results. Further discussions with the manufacturer offered the possibility that fill, degassing, and "settling" procedures were faulty, so a fairly lengthy program of testing capacitors using various refinements of fill procedures was initiated. In one sequence, a new capacitor which had never been filled with oil was filled with sulphur hexaflouride which has similar dielectric strength to oil at moderate pressures. Nothing showed that the capacitors could ever be safely operated at voltages higher than 12 kV rms, in spite of test-cup hi-potting results indicating corresponding peak voltage withstands three times this. The results reported in reference (10) NELC 2761.

Although, by this time, one of the Omega BIA's was on hand for intended high voltage rf qualification tests, no such tests were now possible, but measurements of the grading across the assembly, using the sphere gap voltmeter method, was determined for several configurations of rainshield and open grading ring hardware, with the insulator at ground level as at the Omega stations and mounted on a pedestal modeling what would have to be provided at Annapolis to occupy the ten-foot space between the foundation and the tower base. The indications were that for such an arrangement, the grading could be satisfactorily controlled and, provided the high voltage criteria of withstand and flashover for dry and wet conditions could be met at rf, the insulator would be usable at Annapolis. The

design and construction of a truly high voltage facility now became of the utmost importance and was undertaken immediately following the conclusion of the Omega grading tests in early March 1973.

7.2 NELC/LLL 500 kV Test Facility

Sufficient experience had been gained by this time to permit fairly good estimates of test circuit impedances for both dry and wet conditions across the test piece. The variations could be quite large, and, for a sharply tuned circuit, the resultant changes could be destructive to the driving source. Accordingly, a careful series of compromises was undertaken to arrive at a system that would not overwhelm the driving source, assumed to be one of the Lualualei PA's, and permit testing to at least 450 kV rms under spray wet conditions within the limit of 500 kW delivered to the circuit through what would be a considerable mismatch that could not be compensated for with the existing network. The calculations resulted in a letter report, here furnished in its entirety as Appendix E. A thorough discussion in this text at this point of the details of the design basis would be out of place and overlong.

Very briefly, the outcome was a circuit mounted on the concrete pad provided for the capacitor stacks, with an extension thereto, the whole shielded with hardware cloth for a ground plane and tied to station ground. The circuit components were two 12-foot high, 12-foot diameter, 55-turn coils connected in series aiding to give 17.5 μHy inductance in series with the helix house components and fed by a copper tube downlead permanently mounted to the helix house face, and also in series with a "bedspring" capacitor 60-feet square and 18-feet off the ground, having a capacity of roughly 1100 pf. The high voltage conductors were carefully

sized, based on previous experience and calculations, to control gradients to less than wet corona inception levels at the intended design voltage of 500 kV rms at 28.5 kHz. Selection and stressing and grading of the station post insulators holding up the assemblies and the details of the actual construction would make a complete novel-length story in itself. Extensive use of the Chollas Heights facility was made to conduct model studies, both in air and in an electrolytic tank to confirm computed estimates for circuit values. One particularly delicate matter was the support posts for the coils, which in the end, were made of hardwareless station post porcelains glued together nine high, end-to-end, with casting resin and braced with three-inch diameter pvc schedule 80 white tubing sections whose ends were fastened with resin-saturated fiberglass cloth tape wrappings at the station post joints.

The design occupied the better part of spring and early summer of 1973 and the construction was undertaken immediately following Labor Day by station forces, including the PWC riggers and a large crew of welders, technicians, and laborers from Pearl Harbor. As a rough approximation, based on the author's recollection of the number of persons and the length of the days spent, in the six weeks to completion, shortly before Halloween, about 2½ man-years went into the erection of the circuit. Immediately following a demonstration performance for RADM Paddock, at which the circuit was fully tested to breakdown for the very first time, it was used for conducting qualification tests on the rotating I.U.'s.

It is worth mentioning that the arc-free test voltage attained by the circuit itself was 580 kV rms, or more than 800 kV peak. A plan view of the installation in its later versions is shown in Figure 7 and an electrical diagram in Figures 8 and 9.

The updated procurement specification, Appendix F, required extended test times of several hours to permit a statistical measure of interruptions under wet conditions. Thus, the usual criteria for withstand used by the power industry were not applicable and, by comparison to their requirements, the supply of standard water was orders of magignitude greater because of the spray wet conditions under which the determinations were to be made. It quickly became evident that the demand for distilled water to mix with local tap water to produce standard conductivity would overtax any supply, including SubBase, Pearl Harbor, and therefore the facility would have to be its own manufacturer of such water. The method finally used consisted of a deionization plant in which a continuous flow process using a resistivity cell as a control produced distilled water mixed in the right proportion with tap water for the standard conductivity in 6000 gallon batches. Except for the necessity to rejuvenate the two resins in the system, the installation could have been run continuously at a rate of about 1500-gallons per hour. In view of the rate of demand for some of the wet tests, a continuous capability of about 8 hours duration was accomplished. The basis for the design of this system is included here as Appendix G.

8.0 GUY INSULATOR AND I.U. DEVELOPMENT TESTS

By November 1973, it was apparent that the chances were heavily against any kind of successful fix on the Lapp BIA, although some aspects remained to be tested, notably the possibility that some kind of petticoat configuration could be bonded onto the existing surfaces. In any case, the existence of the new High Voltage Test Facility offered the capability of trying various remedies, if not at leisure, at least without the possibility of a collapsing tower in the event of insulator failure. Also, another opportunity of assembling the Lapp BIA under controlled conditions was possible. Moreover, the Omega (Continental) BIA intended for the Argentina installation was available for test and would be put through the same sequence as planned almost a year earlier with the oil capacitor test bed; additionally, certain tests of surface contamination, including salt water and ice were contemplated. Finally, there were obvious aspects subject to improvement on the rotating I.U. It was felt by NELC that a simple improvement of grading by installing and extension of the dunce-cap rain shield would take care of most of the rf problems; Lapp, on the other hand, felt that the addition of a third segment in the insulating column was appropriate. There was considerable controversy over this, mainly because the history of a similar such fix for the top-load insulators in the old NPM triatic showed that the lack of suitable grading to take full advantage of the third segment improved the flashover limit by only 10% compared to the two-element string. At any rate, the decision was made to conduct comparison tests on these two-deck modifications in comparison with the three-deck redesign, as well as further modifications on it if these

were felt desirable. It was intended to test the new larger Continental BIA as well when it became available, inasmuch as such tests were required by the new procurement specification.

Appendix H is furnished to show the intended schedule of tests that were to occupy the test facility up to about the middle of February 1974. In the event, considerable variation from this sequence was brought about, first, by the availability of the Continental BIA mockup for rf testing and its subsequent failure, and second, by the considerable shock of the failure of the Omega guy strain insulators. Although the schedule was varied, most of the items called out in the test plan of Appendix H were, in fact, accomplished, and in addition, many more configurations of the anti-corona hardware for the I.U. were tried than were originally planned. It also goes into considerable detail about the calibration of the test facility, because this had to be unimpeachable in the event of a marginal failure of a contractor-supplied device intended for acceptance under the I-157 specification, Appendix F.

8.1 Rotating Isolation Unit

Initial testing of the Lapp two-tier I.T. showed that it failed by a wide margin satisfying procurement specifications if they were interpreted to mean VLF voltages, even though a pass had been accepted long since for all the 60 Hertz criteria. DRO, WFO, DWS, WWS, and wet and dry corona inception were all failed at VLF. Moreover, an indisputable internal arc occurred during dry flashover tests, and there was incontrovertible evidence of local burning of the internal porcelain surfaces when the unit was disassembled after the event. Grading tests by the sphere gap voltmeter method indicated a 65%/35% division top to bottom and through several reconfigurations using flexible tubing grading rings, it was shown that when adjusted to equal grading by a top rain shield extension, the unit would meet specification. While the three-tier assembly showed similar failures and similar improvement, it offered no advantage over the two-tier unit, contrary to the claims made by the manufacturer. The entire sequence of tests on the I.T. extended over a period of six months, starting in early November 1973 and involved a total of 26 or more arrangements of corona rings and grading rings for both two- and three-tier units. In the interest of brevity, these are not described in detail, but final recommended and adopted outcome is depicted in Figure 10. In all events the rotating I.U. finally died a natural death because of persistent troubles with bearings and gas tightness and was supplanted by a three-deck isolation transformer tested in 1975 and 1976. This is discussed in a subsequent section.

8.2 Lapp BIA Fixes

In December of 1973 the Lapp BIA incorporating all the improvements to date, such as the extended top rain shield, clean interiors, local-field shaping rings, and multiple ball-to-shield gap protective device was installed on the test pad and a comprehensive and definitive series of DFW, WFO, DWS, WWS, DCI, WCI tests conducted. As found before, the controlling aspect was the formation of connected sheets of corona in water on the surfaces of the smooth cones under spray wet conditions. In an effort to alter this, a contract had been let with SAI to investigate the practicability of casting RTV petticoats on the outside surfaces of the cones under field conditions. As a part of this research, the properties of specially prepared smooth, hollow porcelains with and without such petticoats, constituting in single units models, so to speak, of the elements in the Lapp BIA, were investigated for dry and wet conditions. At this remove, it is not possible to say what, if any, improvements were obtained by cast-in-place petticoats on the test objects. For the Lapp BIA, some improvement was noted and, had it not been for the evident difficulty in obtaining homogeneous, smooth surfaces without inclusions or voids with the casting method used, consisting of adding successive beads to a flange-shaped surface directly bonded to the porcelain with a caulking gun, it is likely that such a scheme might have been adopted for the Lualualei BIA's except for (1) at east tower it was already evident that the BIA had to be replaced and (2) a destructive surface arc took place across one of the units from particles of dirt during a "contamination" test. The resulting etch mark made the continued structural integrity of so-modified Lapp cones at least

questionable, and so it was finally concluded that no recourse existed other than replacement with a BIA containing petticoated porcelain units.

8.3 Omega BIA Modifications

Tests of the BIA intended for installation in the Argentina Omega station were addressed in the test plan of Appendix H. It was found early in the sequence that, in its existing form, it was under specification for wet conditions and so various modifications were attempted, the most significant being raising the height of the rain-shield by about ten inches and adding small collars at the grout-to-hardware joints of the individual porcelain to reduce local gradients and to protect the epoxy seals from corona damage. In the configuration intended for Annapolis in which the BIA was mounted on a raised pedestal approximately four-feet high, an additional ring was added around the periphery of the top corners for the pedestal so as to be about the same major diameter as the top rain shield. It was qualified for use at Annapolis under the restriction of 170 kV for long-term wet withstand to meet the daily maximum allowable interruption criterion of aggregate three minutes in 24 hours.

8.4 Continental BIA Tests

The first of three extraneous test series in relation to that already planned for this period was an attempt to improve the total procurement schedule for the replacement BIA by carrying out the same tests as for the modified Omega BIA on the mock-up version of the new larger device. The concept was that aside from structural considerations, the new BIA could be qualified by producing a pass on the mock-up instead of testing the actual insulator. This followed from the 60 Hertz tests at A.B. Chance in mid-December 1973, at which the mock-up passed the requirements by a wide margin. This statement is not true of the protective gap hardware which investigative tests showed still needed substantial improvement. But at this time, the major concern was for the BIA itself.

The original version of the mock-up hardware which greatly resembled that of a scaled-up version of the Omega BIA, failed every VLF test criterion called out in the new procurement specification. The original BIA hardware design is shown in Figure 11. It quickly became evident that the controlling aspect was the configuration of the rain shield/grading ring system, especially the top rain shield which produced a high field concentration at its outer edge. An ad hoc effort for redesign was quickly undertaken from which it was not too surprisingly found that by inverting the top rain shield and adding extra rings beyond the existing boundaries of greater minor diameter in a progressively higher location, an approximation to a Rogowski surface of revolution could be produced that showed promise of satisfying requirements. A conference in Washington with the project sponsor, followed by a design review in Dallas with the contractor in early March, produced contractor-supplied hardware for tests in late

April and early May 1974 that convinced him that the results observed in January were valid and gave a configuration that all agreed in a second design review would probably satisfy VLF requirements. This final design was frozen in May 1974 as a direct result of the development of tests directed by NELC.

The significant difference between test results at 60 Hertz and at VLF deserves some comment. In earlier experimentation on samples of wire in a concentric device in which purely radial fields were available, comparison of 60 kHz with VLF (10 kHz to 60 kHz) seemed to indicate a downward trend in corona inception levels with increased frequency. This trend was similar to what had been reported years earlier in connection with so-called standard rod-to-plane gaps. A difference depending on frequency was thus not unexpected; moreover, the differences between ANSI procedures and the spray-wet conditions for WWS and WFO called out in the new procurement specification were appreciated inasmuch as results were in hand for the comparisons at Lualualei and at Chollas Heights from the previous year and a half. But a one and a half-to-one difference, 60 Hz versus VLF was hardly being looked for. The experience with the new Continental BIA seemed to show definitively the highly artificial nature of the ANSI procedures and also the difference between clean laboratory conditions and outside tests in which active spray deposition is a condition of wet tests. The reasons for the large difference in dry test results are not so obvious and were never really resolved. Extensive and repeated calibration of the rf test facility using substitute standard

reactor techniques and comparisons with accurate ammeters metering current into standard resistors, even accounting for the fraction of current bypassing the bedspring capacitor high voltage attachment point for the test piece, never failed to give indications of accuracy to within 2% and the calibration of the A.B. Chance 60 Hz and impulse testing facility was never called into question, so the differences had to be accepted as real. Dust, dirt, and even insects were all observed factors in lowering the outside test results, but by no means could be regarded as the only reasons.

8.5 Other Tests

The second and third added test series disturbing the originally planned scheduled were first, the evident difficulties with the BIA protective system and second, the dramatic failure of the center stabilizing element of the pentapost insulators used in the base insulated Omega towers. It is worthwhile to describe these tests and their antecedent history in a separate section.

8.5.1 Gap Tests

While the new specification required the BIA to meet definite flashover and withstand requirements, it also described independently the characteristics of a protective gap system. Because of the previous failures of the various gaps tried out with the Lapp BIA's and the evident difficulties with the existing Omega BIA gap, there were several configurations attempted with the Continental BIA on an experimental basis. These are sketched in Figure 12, and were basically four configurations: a large sphere on an inverted "L" shaped support arm, much as for the Omega BIA, looking at the top rain shield; the same, looking at an outward projecting similar sphere mounted on the rain shield; an enlarged cylindrical rod with sharply squared-off end looking at either the rain shield or the rain shield-mounted sphere; and an enlarged version of the horn gaps used in the PA capacitor surge protective system. These were all tried at A.B. Chance as part of the 60 hz qualification tests in December 1973 and calibration curves were drawn for them both for 60 Hz flashover and for impulse response. Additionally, the wet behavior was studied

in detail, from which it was found that the uniform field, closely spaced, sphere gap gave test results about half those when dry, while the non-uniform field devices, such as the horn gap and the rod-to-sphere breakdown at very much closer voltages in confirmation of observations at Chollas. The basis seemed to be that sphere of ionization forms around the small electrode at relatively low voltages wet or dry and becomes the controlling aspect of the ultimate breakdown. In any case, the non-uniform field gap gave promise at 60 Hz of satisfying specification requirements, and so was made subject to the VLF tests along with the BIA mock-up.

With the considerable help of Dr. F.R. Kotter of the High Voltage Laboratory of the National Bureau of Standards, these proposed protective gaps, as well as many other configurations including cascaded rod-to-sphere gaps were studied at Lualualei in January 1974. In conjunction with the BIA hardware development, in February and March a continuation was undertaken in which not only double gaps, but multiple rod-rod and rod-plane gaps were investigated in detail.

The outcome of these experiments was that a non-uniform field type gap would be vastly superior, in providing constant and predictable behavior under most environmental conditions, to a uniform field gap whose response is sensitive to surface perturbations on the (locally) near-plane surfaces. However, because of the highly divergent nature of the field near the small electrode, breakdown field strengths are reached at relatively low gross potentials across the gap, so that to withstand very

high voltages such as required by the BIA procurement specification, more than one such gap in cascade would obviously be required. It quickly became evident from tests carried out in April and May 1974, that one desirable configuration would be a stack of up to ten gaps in a voltage grading device consisting of wide closely spaced plates acting as the plane side of rod-to-plane gaps; however as development and provision of such a device was well outside the contractor's scope defining the BIA, his effort was confined to balancing the wet-dry performance versus electrode end radii for non-uniform gaps consisting of a rod (or earlier a small sphere) working against center corona rings on the BIA, one each for each deck of porcelains. Ultimately, this rather simple scheme turned out to be marginally acceptable and forms the present protective system on the Lualualei BIA. The ring system for Annapolis turned out to be self-protecting and no gaps as such were installed.

Because of lingering doubts about the effectiveness of the contractor's protective gaps, it was felt worthwhile to continue the investigation of the properties of multiple gaps to arrive at a lightning arrestor concept that would be nearly immune to environmental conditions and completely independent of any of the tower base components. This development culminated in the Multiple Gap Device which was considered for adoption at each of the five VLF insulated tower bases, but never actually installed. Its history will be discussed in another section. The gap results were reported in Reference 11.

8.5.2 Early Guy Strain Insulator Tests

Although supposedly required to operate at up to 250 kV rms as the topload extremities for full power input at the lower portion of the design VLF band, (or about 220 kV at the tower base) and in all four cases similarly configured as a single-tower-supported umbrella topload (Annapolis is a hybrid with a hexagon topload supported at the center of a base insulated tower and the outer corners insulated by fail-safe strings from grounded support towers), the two Lualualei communication antenna towers came out with quite different numbers and configurations of topload and guy insulators from those at the two Omega stations using base insulated towers. The basic concept was the same for all, namely that the topload guys were not considered as structural supports for the tower and need only be self-sustaining; hence, they need not be of "fail-safe" design and thus impose tensile forces on the insulator elements. The tower support guys, on the other hand, were required to be such as to work the elements in compression with the hardware configured in such a way that failure of the insulator would not lead to separation of segments of the cable portions. The successful bidder to supply the insulators for the communication station rated insulators considerably more conservatively for guy breakup use, based on 60 Hz tests, so that the design model studies for numbers and ratings and locations of such insulators resulted in not fewer than six and as many as eight guy breakup points while those for the Omega towers, in part based on the supposedly higher

electrical ratings of the other successful bidder for supply, gave four such breakup points. In retrospect, it appears that had the qualification test results that led to the controversy referred to in Section 3.3 been, in fact, rejected, a redesign might have led to the incorporation of more breakup points, but it is doubtful that all of the ensuing troubles would have been avoided thereby. It turned out that the withstand tests for both Omega and communication guy breakup insulators at VLF gave similar results, but the corona inception results were quite different, and this may have been the crucial aspect.

In the communication stations, there were no electrical failures that led to subsequent mechanical problems, although there were troubles similar to what is experienced at most high voltage base insulated installations, namely, that certain conditions of electrical activity and/or precipitation lead to guy insulator "sparkling" having nothing to do with direct lightning strikes or with insulator ratings such as wet withstand, per se. This phenomenon appears to be a kind of Van deGraff charge transfer between guy segments of different potential by the close-by passage of particulate material such as dust, snow, and rain or sleet. It is not a triboelectric effect, but an induced charge mechanism. It does not take place when the tower is electrically neutral. This author has been present on several occasions when the events take place in what is an otherwise very usual and uneventful operating situation, in windy, snowy (or rainy) weather.

Not long after the North Dakota Omega installation became operational, on the other hand, two distinct events took place. One was a topload main insulator failure, subsequently diagnosed as an internal burn in a void, a condition possible because of the construction features of the insulator (to be dealt with subsequently); the other was what was dramatically described as a rainstorm of porcelain fragments from failures in the center post of the pentapost guy strain insulators. These fragments showed unmistakable evidence of high-temperature high-power burning from flares and/or arcs. Although the "sparking" phenomenon had been reported for the tower, it was fairly evident that the damage was something that could not be explained by the occurrence of intermittent single discharges of that sort; these looked as if they had been brought about by extended operation in a strongly ionized condition in wet weather. The events had taken place well before the construction of the Lualualei/NELC Test Facility, and a decision was made that realistic qualification tests should be undertaken during the time that the facility would be in use for the base insulator tests.

In February 1974, initial testing of the Q9A and Q9B series took place. DFO, DWS, WWS, DCI, WCI were all measured, the wet tests being under spray wet conditions. The insulators were suspended from a 50-foot mobile crane in normal orientation, with the bottom end of the insulator set connected to the bed-spring capacitor by a flexible trunk made of metal-reinforced air conditioner ducting. Immediately, a controversy arose concerning the reversal of the "high-voltage" connection,

with the manufacturer's representative maintaining that a corona ring was of no value on the low potential side of the assembly. Apparently, a confusion existed concerning the significance of field concentration and voltage with reference to an abitrary ground, which was resolved only with difficulty. The series of tests were repeated with the insulator bare of anti-corona hardware, with the configuration of hardware called out in the installation sketches and with modifications described below developed in the course of the experimentation.

In its original quadripost form, the apices of the assembly were provided with corona rings in pairs, mounted to the sides for the end caps in a manner resembling ear muffs. When the fifth center station post was added, provision of similar anti-corona protection required modification into what has been termed stirrups. A sketch of these items is provided in Figure 3. The requirement for any anti-corona devices at all for a particular unit in a complete guy assembly apparently was determined by the designer in terms of voltage at the location, the voltage difference across the insulated gap, but not on local gradients. Nor was the degradation of withstand particularly under wet conditions by the presence of the fifth post taken into account, mainly because of the disputed nature of the qualification tests. At any rate, tests with the corona hardware in place at all apices of the assembly, whether or not called out as required in the installation drawings, showed that the rating of the insulator for withstand was not improved thereby nor was the basic problem avoided

which night observation of corona inception showed was strong active flares taking place across the endmost petticoats of the center post under wet conditions well under the long-term withstand for the insulator. The location of this high intensity discharge was exactly as indicated by the burn damage evident on the fractured porcelain.

In an attempt to cure this condition, a spring wire ring similar to the collars installed on the Omega BIA to protect the grout joints was placed around each end cap in order to provide a location for the formation of the flares that was removed from the actual porcelain surfaces. The diameter and location was such that the ring projected beyond the edges of the petticoat. Additionally, small collars were installed around the grout joints as in the Omega BIA for the same reason. The outcome was a failure to improve corona inception levels wet or long-term withstand levels, but the insulator could now be operated in a condition of active-corona for extended periods without damage. NELC recommended that a production version of these modifications be obtained and installed in the existing insulators after qualification tests at the Lualualei test facility. This was, in fact, done later in the year. In July 1974, comparison tests (over the objection of the insulator supplier) were run using the Lapp compression post fail-safe insulator in two sizes, as installed at Lualualei and Annapolis, which showed similar flashover and withstand levels, but not so much tendency for early formation of corona, mainly because the hardware configuration was different and more gently curved. A drawing of the assembly is shown in Figure 13. Arcover took place mainly between

the portion of the saddle in which the top of the station post was nested and the linking arms to the opposing frame into which the bottom end was nested, so that the insulator hardware, to a large extent, protected the porcelain. Under very heavy spray wet conditions, an arc could be induced that followed a path very closely along the extremities of the petticoats, but this took place at levels seldom expected in a guy assembly in view of the actual voltages in the system and the presence of at least 50% more individual units in the string than was the case for the Omega towers. Put another way, the Lapp units were not intrinsically different from the Continental units, in any respect, except the wet inception level and in their application, had an advantage in carrying, at most, two-thirds the voltage demanded of the Continental units. Neither assembly could be significantly improved although the attempt was made in both cases, as already described for the pentapost, and by applying collars around the porcelain to insulators and by placing hardware cloth sleeves around the linking arms to increase the radius of curvature and reduce local fields in the Lapp units. Improvement mainly consisted in the control of the arc path, not in the voltage at which the arc occurred.

9.0 DESIGN FINALIZATION, INCLUDING LATER GUY INSULATOR TESTS

In the period from early May through mid-July 1974, continuation of the above described developmental efforts on the BIA, the guy insulators for Omega, and various combinations and types of gaps and protective devices took place in rotation, with most of the measurements on the BIA and Omega insulators now taking place using contractor-supplied protective corona hardware configured as found and recommended by the NELC conducted development tests. A semifinal form for the multiple gap device was defined,and procurement was undertaken for insulators and hardware for final tests to take place on the "production" prototype later in the year. Additionally, single deck tests using combinations of the Cerelap porcelains in the Omega BIA were conducted and a test on Unit 69 of the Stemag insulators for the LLL BIA was performed using a continuous soaking to see if any destructive arcing had been taking place in the porcelain-to-epoxy grout sealant interface which had been found to have separated sufficiently in some of the units to permit relative rotation of the porcelain columns and the metal end caps. Later dissection of this unit failed to show any harmful effects, although there was evidence that water had penetrated the fine crack by capillary action. The Q7A and Q7B quadriposts were tested in a manner similar to the pentapost with similar results for ratings with the contractor-produced hardware recommended by NELC, but, of course, there was little of the same concern for the protection of the unit as for the pentapost. Firm recommendations were made to CHESDIV and

PME 119 on retrofitting antenna hardware to North Dakota and Argentina guy insulators. In conjunction with all these tests, the AGA Thermovision infra-red conversion camera was used to record temperature rise in the units while under test -- this equipment had initially been tried in January 1974 on an experimental basis and found to be of the same order of accuracy as NAVSEACTPAC's thermister and much more convenient to use, after being suitably screened from r.f.i. Lastly, a finalized version of the NELC mods for the two-tier insulation unit was tested for acceptance and the configuration was described in detail to NAVFACCHESDIV for their preparation of production drawings.

All these finalization tests involved DFO, DWS, WFO, WWS, DCI, WCI, and, in some cases, heat rise tests on several modifications as for developmental tests; it is not possible to say how many individual modifications were so tested, but there were seven or eight for the Omega insulators, as many as 22 for the BIA, four for the Lapp guy insulators, and, as before mentioned, a total in the entire series of more than two dozen for the I.U.'s. Appendix I is indicative of the effort for the BIA and shows the final hardware configuration adopted.

Apparently, as a development independent of the efforts of SAI, NCEL devised a computer program for calculating complete field distributions around the insulators of any longitudinal cross-section, provided they display rotational symmetry. Ongoing work is now directed at removing the requirement of rotational symmetry. In the very early days of the design efforts by CEMCO, use was made of electrolytic modeling in the

form of plane sheet sketches of silver paint on aquadag-coated paper, similar to a two dimensional electrolytic tank, to predict location and distribution of critical equipotential surfaces and hence field concentrations. While these were certainly indicative and of undoubted aid in gaining a qualitative idea of distributions, they are in principal wrong because of the two dimensional nature of the representation, and thus not much reliance can be placed on them for quantitative estimates. The use of the computer program finally became crucial in attaining the final configuration for the Continental BIA hardware; it also showed beyond doubt that the smooth conical surfaces of the Lapp BIA elements could be expected to be in trouble immediately when wetted. During the period when single element tests were being conducted at Lualualei on a pedestal, such as the Ceralap deck and Cervit block, a rerun was made with a single Lapp cone placed under a large plane sheet equipped with a large corona ring that should have provided considerable equalization of fields. The author regrets that the inclusion of the resultant nighttime photograph of the entire insulator enveloped in a sheet of corona cannot be included in this report. During the test the withstand voltage declined to below 20 kV.

10.0 CONTINENTAL BIA ACCEPTANCE TESTS

The final design review at the Continental plant in Dallas, Texas took place in the last days of May 1974. The configuration of hardware presented for test in mid-July 1974 was substantially that agreed upon with a few minor variations of dimensions in the innermost rainshield location that could be adjusted to a small degree. Official acceptance tests commenced 22 July 1974, consisting of the following:

- DFO, WFO, DCI, WCI without protective gaps
- Gap calibration, individual tiers, wet and dry
- WWS with gaps set for recommended position based on calibration
- Extended heat rise tests (24 hour) in conjunction with interruption tests, with 12 hours of spray in 2 hour shots

The only test difference from that already described above and differing from the modified ANSI procedures was the interruption tests. These consisted of measuring the number and duration of arcing or flare events that under 250 kV spray wet conditions would result in a cumulative down time for the transmitter of more than three minutes in 24 hours. To discriminate between "spontaneous" events and those that might be induced by fluctuations in transmitter output in response to power line transients, a memory voltmeter was placed on the power line feeding the station, as part of the test condition requirements. Otherwise the procedures were the same as used hertofore, with pass criteria stated in NAVELEX specification I-157.

Although no interruptions were experienced, so that power line variations for these tests became a moot point, it was startling to all concerned to observed the poor regulation and the occurrence of large transients in the commercial power source. The output of the transmitter under the conditions of loading presented by the wetted insulator and test circuit through the mismatched coupling network appeared to hold to within 5% in spite of the source variations; it was agreed, however, that this aspect was, by good fortune, overlooked in the controversy that raged about the mysterious overvoltages as possible causes of failure in the Lapp BIA and protective system two years before.

It should be mentioned that the final gap system adopted consisted of one simple 2½-inch diameter rod with hemispherical end in each tier, projecting upward from below and looking at the corona rings in the next adjacent level; the gap setting was measured as the distance between the rod end and the closest such ring. They were adjustable in one-inch steps from 20 to about 38-inches, so as to include the setting proved likely in development tests of multiple rod gaps. Because of the wide spacing and relative high voltage (250 kV rms by specification) for wet withstand, they acted as a hybrid device, neither definitely non-uniform field nor uniform field, and hence, their response under wet and dry conditions was markedly different, though admittedly within specification. Moreover, the cascade of two gaps was just sufficient to bring the randomness observed for previously used single gaps under good control and in operation, no subsequent difficulty was experienced like that from the early models to mid-1972.

BIA serial No. 1 was accepted officially on 26 July 1974 as having passed I-157 rf specifications; it had immediately prior to the Hawaii tests been qualified under the 60 Hz portion of the specification at A.B. Chance; its companion passed in mid-August. The Lualualei towers were jacked in early August and early September and BIA No. 1 went under West Tower on 10 August 1974. BIA No. 2 performed identically to No. 1 in all respects except for WCI; one of the Stemag upper-tier units required emplacement of a spring collar around the porcelain to metal epoxy grout joint to obtain a pass. It was then placed under East Tower.

BIA serial No. 3, intended as the unit for Annapolis, was tested in October 1974, but as the Omega BIA on the pedestal was already in place there, it was simply place into storage, ultimately in the unused helix house No. 2 on Greenberry Point. It satisfied all requirements without modification. It presently serves as a source of possible spares for the other BIA's in current use. Figure 14 shows the final version of the CEMCO BIA hardware developed by NELC.

11.0 ISOLATION TRANSFORMER

During 1974, a specification was written with NELC consultation by CHESDIV NAVFAC under which a procurement was undetaken for a three-deck isolation transformer similar to those used in the past, in which toroidal oil-immersed transformers were used to supply 60 Hz power to the tower lighting system across the 250 kV rf base insulator. The procurement specification, 21-75-0043, resulted in Contract N62477-75-C-0043 to Decca Austin Insulator Corporation of Branson, Ontario; after a design conference in December of 1974 and various correspondence concerning the rf specification requirements with CHESDIV, the first item was tested according to the specification requirements similar to those for the Continental BIA but with the extra properties of placing 60 Hz power at the high rf voltage side of the gap with a designated efficiency. These tests entailed modification to the LLL test facility so as to provide a dummy load on the bed-spring capacitor to absorb the 60 Hz power; the qualification tests were conducted in the last week of October 1975. The rf specification requirements were as severe as those for the BIA in all respects having to do with DFO, WFO, DWD, WWS, DCI, WCI and interruption frequency, as well as requiring 60 Hz power delivery with a required efficiency and regulation. It also defined grading across the stacked units and a protection system similar to that for the BIA, only appropriately sized for the three decks in contrast with the two used in the BIA.

Serial No. 1 was supplied with adjustable grading rings whose positions, when by experimentation were found to satisfy the specification

requirements, were built into the hardware for the succeeding four units. The gap system was similar in the outcome, although initially consisting of rod-sphere gaps which were designed out of the system by test, to that of the Continental BIA. The recommended setting was 18-inches per deck, later revised downward to 16 inches.

A marginal pass was obtained involving a suspected internal breakdown of one of the isolation transformer segments under an applied voltage later proved to be in excess of the specification requirements for DFO; the subsequent units tested in March 1976 passed without question. In the first unit, there proved to be an apparent rf shielding problem in the 60 Hz voltage regulator which was subsequently corrected. Apart from subsequent breadkown in one unit, the I.T.'s have performed satisfactorily at all five insulated tower locations.

As part of the specification requirements, two cascaded units in any combination were required to perform to an rf withstand of 250 kV with the third element failed (tested as a shorted segment for rf). This requirement was also successfully met.

Since by the time of this procurement, the disasterous properties of hydrogen-refined transformer oils had become evident for the PA capacitors, it was a known requirement that acid-refined oils be used in the I.T.'s and this type was a defined part of the acceptance criteria. Filling procedures were carefully monitored by NELC and carefully executed by the supplier. Oil quality was analyzed before and after electrical test.

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12.0 MULTIPLE GAP DEVICE

The four occasional of investigating the properties of arc gaps of various sorts carried out during the 1974 insulator tests after the 60 Hz gap qualification measurements led to trials in July of cascades of rod-rod and rod-plane gaps as possible protective devices for very high voltage insulators.

These trials led to a semifinal version consisting of a stack of fourteen metal sheets of varying diameter for capacity grading purposes equipped with flexible metal tubing anti-corona rings at the edges (later found to be unnecessary) mounted on a coaxial column of station post insulators that were available at the test site. The electrodes were sets of 3/8, 1/2, and 3/4-inch diameter aluminum rods with threaded concentric studs and made in modular sections so as to be adjustable in ½-inch steps, the whole set being sufficient in number to set up either a rod-rod or a rod-plane system. The grading was determine and the individual gaps were set to correspond as closely as practicable to the grading, so that no single gap would be controlling, although as a practical matter, it is not possible to make them fire exactly non-preferentially.

Experimentation in September 1974 determined that for the voltages at hand, a stack of 10 or 11 gaps would be sufficient; and while in some respects, rod-rod gaps might be preferable, the rod-plane gaps could likely be mounted in a somewhat shorter overall height. They were placed so as to project upward from below to the next sheet above so as to avoid the

possibility of shorting by connected streams of water under spray wet conditions.

The VLF results were so promising in showing a device whose breakdown characteristics were practically immune to external conditions, that it was determined to proceed with impulse tests at Naval Air Test Center Patuxent River, where there was available a government owned Marx generator adequate to perform the tests. In its final form in which pin-cap insulators were used in triads between each deck for structural stability, it was set up in an electrically shielded hanger housing the impulse generator and a two-week series of wet and dry calibrations was conducted for nine variants during March 1975.

As Appendix K shows, two or three versions were found to satisfy all performance requirements and their adoption was recommended after certain modifications to render the device structurally adequate for wind loads, and after a final round of VLF tests were to be performed. When these last were finally carried out at LLL in early November of 1975, it was found that the pin-cap insulators have such high dielectric loss in the grout joints between the layers of porcelain that they would overheat and fracture, and were thus unsuitable for use at VLF. Therefore, were the device ever to be actually installed, recourse would have to be made to station post support insulators, short enough to keep the assembly to a reasonable height, yet bulky enough to withstand wind shear loads. Within the time and funding available in consideration of the desire of PME 117 to get back to the main business of final development of the VERDIN system (even though it was proposed in the interest of economy to continue the project as an inhouse

development and installation) and because of the dimished sense of urgency due to the absence of problems with the new BIA's and their protective devices, further development of the MGD was not immediately possible, so it was place on indefinite hold.

13.0 HAIKU OMEGA ANTENNA HARDWARE TESTS

Although by mid-1974 the principal difficulties with the base insulated tower insulating system could be regarded as ameliorated, if not cured, other problems cropped up during early high power testing of another Omega transmitting station of nearly a comical nature. These mostly were unexpected occurrence of intense corona on the Haiku spans. Possible causes and cures were investigated on the NELC/Lualualei Test Facility in October 1974, relating mainly to the obstruction marker spheres and to the clamps of the vibration dampers.

13.1 Obstruction Markers

By FAA requirement, the rationale which is beyond the scope of this report, the new six-span valley antenna at Haiku, erected to replace a four-span VLF antenna of wartime construction whose effective height and capacity were not adequate to meet radiation requirements for the final Omega system, was equipped with spherical international orange obstruction markers on spans A and F, the outermost cables enclosing in plan the other four. This was done despite the absence of such devices on the older installation. High power testing in April 1974 brought down several of these in flames, to the consternation and amusement of all concerned. In the absence of these faulty ones, the station could not be operated because the preformed wire mounting clamps remained on the spans and formed sharply pointed electrodes from which corona flares would actively stream; thus they had to be removed. The question now became one of the necessity to remove the remaining markers and/or desirability of

replacing the destroyed ones with new. The cause of the events was also a mystery to be investigated, as nothing of the sort had ever taken place with these when installed according to usual practice on high voltage power lines, even though, like those used at Haiku, they were of the epoxy-bonded fiberglass construction.

A sample of the span cable taken to the Test Facility proved to be too stiff to pull straight as a mounting for tests, so a short section was made up by twisting the correct number of properly sized soft drawn copper wires around a piece of conduit to model the span cables. This was suspended from the edge of the bed-spring capacitor with its ends shrouded to prevent breakdown in unwanted locations, and the marker ball under test was wired to the exposed stranded section in the usual manner.

Application of rf voltage showed that even when wet, destructive corona only took place for levels higher than those on the spans, and under these cw conditions, the usual failure mode was the initiation of corona in water drops at the separation between the flanges joining the two halves. After ignition of the epoxy from the corona, the carbonized tracking of the outside surfaces hastened the process through the formation of strong corona flares. The final stages involved intense flaring and burning around the embedded portions of the mounting brackets. The internal conductive Aquadag coating appeared to provide no effective rf shielding of the sharp points of these brackets. Thermagrams taken during the tests clearly showed hot spots in the location of the embedded clamp ends as well as around bolts and other hardware. Once initiated, the burning process and

corona flares continue at voltages well below those on the spans. The initiation of the destruction on the span was surmized to be from charred tracking resulting from a surge caused by a known lightning strike on the spans prior to high voltage testing, offering exposed conductive points from which flaring could start at the rf voltages used. The final recommendation was to discontinue use of the markers, although this author felt that if such was required, spun aluminum replacements could have been fabricated.

13.2 Vibration Dampers

The wire surfaces were marred at locations where vibration dampers had been installed and some concern was expressed about the cause of these marks. High voltage tests of the dampers on the test span section at Lualualei showed no evidence of arcing or "sparklers" from clamp looseness, so the conclusion after metallurgical examination at Pearl Harbor was that these marks were from abrasion or corrosion.

13.3 Other Tests for PME 119 and NCEL

A detailed program of direct inspection of the spans and night observations through a 60-power telescope for the possible presence of corona and grounding resistance for the span halyards is not really relevant to this report, but is included as a part of Appendix L, which is a trip report written at the time containing the high voltage test results as well. In addition, however, the first test of a high strength synthetic organic material for possible use as topload guy insulators was conducted, but results were so discouraging that they were never really reported. This is discussed below.

Another test object for the short test section of span material was a remote telemetering transmitter for sending strain gage information to a receiver on the ground which NCEL proposed to use for measuring forces in the topload spans at Cutler. This device proved to be usable only after high voltage tests proved what should have been obvious, that its configuration especially the transmitting antenna was grossly unsuited for use in a high intensity rf field and a suggested redesign of the package external shape and internal filtering were provided.

The Philadelphia Resin Company is one of several makers of high strength low loss polypropelene stranded ropes that can be and have in the past been successfully used to guy HF and UHF antennas where voltages and gradients are not severe. Because of the very high strength to weight ratio for the material, its application to the LF and VLF regime would be of considerable impact on tower design and resultant cost. There have

been other kinds of organic material considered and used, one being fiberglass strands looped between end hardware with a compressed outer solid jacket protecting the strain members, others being made up of groups of fiberglass rods anchored in the end fittings, and still others made of numbers of belts of high strength organic assembled in a similar manner. Nylon and orlon ropes have also been used, the latter where a relatively inextensible material is important. All these synthetics share the characteristic of rapid deterioration by exposure to sunlight and high susceptibility to burning if any condition exists permitting the formation of corona on their surfaces. The jacketing material, if any, must thus be inert and enclose the strain member in such a way that dielectric contrast does not lead to internal breakdown and must itself be resistant to weather, particularly in the presence of an ionizing environment. Some synthetics in a cast form are resistant, others are not. Some designs, to be discussed in a separate section below, make use of a porcelain jacket which is not subject to tensile stress.

In small light installations where the occasional replacement of an insulator or a guy is no great problem, direct exposure of the synthetic can be tolerated. The polypropelene insulators supplied by Philadelphia Resin were of this type. Vibration dampsers consisting of loosly draped loops of polypropelene rope on the bed-spring capacitor rounds had already been observed to serve satisfactorily when dry, but in spray wet conditions when corona beads formed on them, they quickly burned, so it was no great surprise when the Phillystran insulators did the same thing. As no anti-corona hardware had been supplied by the company, several configurations

were tried using experimental rings made up of air conditioner ducting as had been done many times in the past during the test series. Although these were of some benefit, it was quite evident that what was really needed were grading rings in the form of the extended baskets used on strings of insulators such as the topload strings at Cutler. In the time frame of the tests, no practicable way to mount such rings on the flexible insulators could be devised, and it was quickly realized that if such a modification were installed on these insulators, they would begin to lose their strength-to-weight advantage in comparison with existing porcelain designs. Moreover, the problem about direct exposure of the material, Kevlar, to weather would remain. Accordingly, further testing for VLF application was halted.

14.0 SYNTHETIC TOP-LOAD STRAIN INSULATORS

Point loads imposed on electrically active top-load elements by the presence of insulators have significant impact on the allowable sag versus stress on the cables, and consequent effect on mean height over ground and so on antenna effective height. The Lapp "double triples," two yoked columns three high of station posts worked in tension (at Haiku a similar arrangement but a triad of columns was used) had as their direct ancestor the multiple assemblies of yoked Locke hollow tubular porcelains used in the older VLF stations. Although never subjected to rf testing, the Lapp units were sized similarly to the Locke units, and since they were made up of petticoated units, they appeared to be very conservatively designed; at any rate, none has ever failed because of the rf voltages imposed, and they are used at numerous locations throughout the United States VLF communication an navigation systems. But their presence in the structures has had significant impact on stressing and cost because of the dead weight loads they impose. Therefore, interest has never slackened in finding a lighter substitute, even after the poor performance of the polypropelene rope insulators. Figure 16 shows a sketch of the concept.

Initially in the Omega final system, a design by Continental Electronics was adopted in which fiberglass rods were prestressed between end mountings in such a way that the porcelain covers would never be relieved of compression and so remained sealed to the end caps even during

the severest of dynamic tension loads in the antenna top-load wires. The rods were protected from weather thereby, and to insure that under electrical fields imposed there would be no possibility of internal corona because of contrasting dielectric materials such as porcelain, air, fiberglass, the assemblies were filled with an insulating material having similar dielectric constant and puncture propterties to the porcelain and the rods. Initially this material was a semi-solid "biwax" which was heated and cast into the partially assembled insulator and allowed to cool slowly enough so that bubbles would be allowed to expell themselves. Shortly after start of high power operations at North Dakota, one of the units failed by internal arcing, and examination revealed that corona and arcing had taken place in an unexpelled bubble. The insulators were replaced by a second set of similar units in which transformer oil was used instead. But there were suspicions about the integrity of these units because of an unavoidable expansion chamber to be left in the insulator (i.e., they could not be completely filled) and the geometrical angle of installation was such that under some conditions a possibility existed that a portion of a fiberglass rod would be exposed. Aside from this, capacitor failures indicated that the oil itself was under some doubt, and so the decision was made to revert to the Lapp units even though procurement had been undertaken from another supplier for an oil-filled set of porcelain jacketed fiberglass rod units for Haiku and Argentina.

Because of its favorable structural and electrical properties, if it could be properly protected from ionizing environments, fiberglass has

continued to be used and interest has continued to be present to find combinations of porcelain and/or synthetic jacketing material not requiring the internal filling with liquid dielectric. Naval Facilities Engineering Command continued to sponsor its Civil Engineering Laboratory to investigate various possibilities, with the result that immediately after the last qualification/acceptance tests on the isolation transformers, a series was run on eleven different synthetic suspension/strain insulators at the NELC/Lualualei Test Facility. These tests proved to be the last for which this 500 kV circuit was ever used, as operational use of the transmitter thence forward precluded its diversion as a power source for tests. Provision of separate 60 Hz power for a 100 kW transmitter dedicated and available for the purpose as surplus from the experimental Norway Omega station was deemed to be too costly.

14.1 Hollow Porcelain-Jacketed Insulators

Two manufacturers had provided basically similar ceramic-jacketed, oil-immersed fiberglass rod strain insulators for use in top-load guys; the one from CEMCO was intended for use in umbrella top-loaded towers in which the top-load elements were not considered an intrinsic part of the tower supports, while the other, supplied by High Power Hardware, was intended as a main structural stress member in a valley-spanning top load. The latter therefore incorporated more and heavier stress members and a larger jacket, but was otherwise the same as the former in overall dimensions for voltage rating. The anti-corona hardware was similar, and initial tests showed that, in both cases under wet conditions, it was controlling to levels below specification requirements. Simple modifications were constructed during the tests and were applied and found to raise the wet characteristics to specification levels. The one outstanding property that could not be tested in the allowable time was the behavior under extended life and because of the suspected problems with the oil filler, they were dropped as candidate insulators in VLF antennas, even though satisfying the usual NELC defined withstand criteria. They also were hardly what could be called really light-weight designs, although they were considerably lighter than the Lapp units for comparable use. Figure 17 is a sketch of the modified North Dakota insulator.

14.2 Organics

The remaining strain insulators were actually intended for power line use as suspension insulators, and some were actually strings of multiple units. These were supplied by various manufacturers, such as Lapp, Ohio Brass, A.B. Chance, Josselyn, Rosenthal, and Transmissions Development Limited (through Permali as the U.S. contact). All but the A.B. Chance, Permali, and Rosenthal units were segmented; the latter were single fiberglass rods jacketed in two cases with synthetic petticoats, while the A.B. Chance insulator was a single rod. The segmented devices incorporated ceramic or glass petticoats jointed with various bonding and stress members, which at this remove and with the time available for this report, cannot be discussed in detail. Some were equipped with anti-corona devices or grading rings, and when tested in the as-supplied condition showed strong susceptibility to failure by burning at the ends in response to corona especially when wet. Equpping with corona rings improved things considerably by reducing local fields, but did not prevent destructive burning except in one case. This was the TDL insulator supplied through Permali.

In contrast with the other insulators which involved RTV and/or epoxy petticoats (except for the Lapp units which were glass) the TDL insulator was encapsulated with a filled aliphatic resin which instead of carbonizing and tracking in the presence of corona, vaporizes into carbon monoxide without release of free carbon and thus does not track. It proved to be almost immune to destruction under arcing conditions, similar to electrical porcelain but without the hazard of cracking. This was true

even when heavily contaminated with wet, salty mud. The performance with the same modified corona rings that were developed for the North Dakota oil-filled fiberglass rod assembly was so outstanding, that consideration was later given to using this type as top-load insulators for a modification to the LF antenna at Driver, Virginia. Although also considered for use at Thurso when it became necessary to replace those insulators, a single column of three Lapp porcelain station posts were in fact employed.

14.3 Vitreous Ceramic Block Tests

CEL became aware of a vitreous ceramic material of very high compressive and shear strength used in the view ports of very deep submersibles by NUC, and was naturally interested in this as a possible replacement for porcelain in applications such as BIA's requiring high compressive strength in a limited space. A massive block was available through NUC for test, and so in conjunction with the last series of guy insulator experiments in April 1976 it was placed on a shrouded pedestal and equipped with large diameter grading rings and subjected to voltages of the order of 200 kV. As for the guy strain insulator tests, the temperature rise was observed and recorded by use of the AGA Thermovision camera. The result was that it rose to a temperature of greater than 115° C in two and one-half hours, with no sign of approaching a plateau and tests were halted when the transmitter became swamped by the unbounded increase in rf loading. As the temperature increased, the resistance decreased in a manner improving the match in a divergent manner so that the block took all the rf power the transmitter was able to deliver. A repeat at a lower voltage showed a similar result, so further tests were deemed useless. Data was recorded that should enable the determination of the dielectric characteristics of this material should this ever be of interest, but this author feels that such is not the case since the device never achieved an equilibrium condition under the tests.

15.0 HIGH VOLTAGE TEST FACILITY FOLLOW-ON

Although not directly relevant to the history of insulator testing in itself, an account of the aftermath of the program seems appropriate, mainly because a lot of effort on the side went into defining a facility that could achieve the same kind of test conditions at a location more convenient and less dependent on the personnel and facilities of an operational communication station.

In 1975, looking to the future requirements of the Navy's insulator procurement problems, alternate locations for a test facility using 100 kW (with possible augmentation to 200 kW) amd maintaining the 500 kV capability were studied and proposed. Because of funding limitations and a decreased sense of urgency now that alternates or fixes were in view for most of the insulator problems at the existing stations, and because of other urgent requirements for continued development of the VERDIN modem, NAVELEX withdrew from sponsorship and left the funding up to NAVFAC. The independent existence of a purely Navy sponsored test facility proved to be impossible, and so with the cooperation of the Air Force, a decision ultimately was made to create a facility with admittedly limited capability at Forestport, New York. The Lualualei facility was placed in a caretaker status in case very high voltage tests would ever be required for proof testing, while the Forestport facility became the test bed for development experiments not requiring voltages more than 120 kV rms (later 250 kV). This is the present status at this writing.

16.0 ACKNOWLEDGEMENTS

This author was priviledged to work with over a hundred individuals including laborers, electronic mechanics, technicians, engineers, managers, and the Commander of NAVELEX in pursuing the described developments. A more dedicated group of individuals would be impossible to imagine and it is unfair to select individuals from the group. Any of the group with whom the author became personally acquainted in carrying out the numerous tests and who chance to read this account, will recognize their participation and hopefully accept thanks for their aid and cooperation in this inadequate form. It would be admirable if several pages could be added to mention all the names and the organizational affiliations, but this would be unwieldy because the temptation would exist to go into particulars, and the section would become as long as the rest of the account.

However, the author would like to mention, particularly in this regard, the small group of engineers and technicians at NELC and NAVSEACTPAC who suffered through most of the on-site evolutions, and the NAVCOMMSTA HONO PWC Chief Antenna Mechanic and his staff who carried out the really onerous manipulation of the test devices and the component assembly of the Test Facility itself. There is no way that the GS rating system can adequately compensate these particular people for what they did. It was purely and simply an above-the-call-of-duty performance that was demonstrated. Similar remarks can be applied to the officers and men of the NRTF VLF Division.

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18.0 TABLES

18.1 Table 1

Brief Chronology of Insulator Test Program

May - June 1972

First VLF Ad Hoc Committee meeting and in-place LLL tests NELC

June - July 1972

Chollas Heights Test Facility construction and NSS BIA tests, NELC
- BIA 1-tier DFO, WFO, DWS, DCI, WCI
- BIA grading, wet/dry, stock and extended rain shield
- Gap tests
- Local field shaping rings
- Cerelap post test

All above 9.8 kHz and 60 Hz

Aug - Sept 1972 - NELC witness

Deco LLL tests
Lapp mods on BIA for inspection and pressurization
SAI mods on BIA for local field shaping

Oct 1972

NELC tests LLL, Lapp BIA with NELC rain shields
- Grading
- Gaps
- Glass brick wall DFO, WFO, DWS, WWS, DCI, WCI

Nov - Dec 1972

LLL oil capacitor HV test facility design, NELC
1/3 scale model tests, BIA's, Chollas Heights

Jan - Feb 1973

$\left.\begin{array}{l}\text{Construction LLL Test Facility}\\ \text{Omega BIA grading tests}\\ \text{Gap tests}\\ \text{Oil capacitor tests}\end{array}\right\}$ NELC

Feb - May 1973

Further model tests, BIA's
Glass brick wall sample tests
500 kV test facility design, air capacitor
Model studies, test facility design
- Coil
- Capacitors
- Electrolytic tank insulator grading tests

June - Aug 1973

- Finalize 500 kV test facility design
- Component procurement

Sept - Oct 1973

- 500 kV test facility construction and testing

Oct - Nov 1973

- Rotating I.U. tests, 2-deck
  - Grading
  - DFO, WFO, internal arc
- Omega BIA tests on and off pedestal

Dec 1973 - Jan 1974

- Lapp BIA tests, DFO, WFO, DWS, WWS, DCI, WCI
  - With and without NELC rain shield
  - With and without RTV petticoats
  - With and without refined field shaping rings
- R&D tests on single small model insulators (SAI)
- I.U. tests, 3-deck
- CEMCO BIA mock-up tests, 60 Hz, A.B. Chance
- CEMCO BIA mock-up tests LLL, 28.5 kHz
- CEMCO gap tests, A.B. Chance and LLL
- Omega BIA on pedestal, final design tests
- Contamination tests, Omega and CEMCO

Feb - Mar 1974

- Omega 4- and 5-post guy insulator tests, LLL
- Lapp saddle-post test

Mar - Apr 1974

- Gap tests, with P.R. Kotter
- Final design I.U. tests, 2-deck NELC model

Apr - May 1974

- CEMCO BIA hardware development tests, Mock-up

July 1974

- CEMCO BIA #1 acceptance test

Aug 1974

CEMCO BIA #2 acceptance tests
Gap tests, single and multiple, with FRK

Sept 1974

Gap tests
Span marker and Phyllistran test

Oct - Nov 1974

Vibration damper tests
BIA #3 acceptance tests
Haiku span inspection

Jan - Feb 1975

Oil capacitor tests at NSS

Mar - Apr 1975

More oil capacitor tests at NSS
Multiple gap tests, impulse, at Patuxent River

June - Aug 1975

More oil capacitor tests at NSS

Aug - Sept 1975

Oil-filled isolation transformer #1
Acceptance tests

Mar - Apr 1976

I.T. tests, acceptance, #2, 3, 4, 5

April 1976

Omega and Lapp guy strain insulator tests
Experimental organic strain insulator tests for CEL

18.2 Table 2

Detailed Chronology

1st Chollas Heights 5-28 July 1972

- Calibrate Transmitter, Antenna Base Volts/Imput Amperes
- Single-deck BIA tests
  - As-built, Lapp
  - Field Shading Rings, Lapp
    - Corona inception, wet/dry VLF/60 Hz
    - Flashover wet/dry
    - Withstand, wet/dry
  - Cerrelap, single-deck, as above
- Ball-ring gap tests
  - F.O., wet/dry
- Square cross-section gap
  - C.I., DFO, VLF/60 Hz
- Single-cone test
  - Internal CI, D/W, FO D/W
  - Internal contaminate
- BIA test
  - FO D/W, single-tier
  - Grading
    - As-built VLF/60 Hz
    - Extended rain shield sold per JCH design
    - Extended rain shield with external conductor enclosure (rain deflector)
  - C.I. D/W, single-tier, as-built

1st NELC LLL Tests, NELC 21 - 29 May 1972

- Voltage rise, East and West tower base vs bushing
- Spurious voltage pickup
- Mysterious resonances
- DFO/WFC
- DCI/WCI without gap, as-built and with grading rings
- DCI/WCI with gap, as-built
- Gap calibration
- Wet welding arc
- Grading
  - As-built
  - Various extended top rings

2nd LLL Tests, DECO/Chesdiv 13 - 22 Aug 1972

- Same as LLL tests by NELC Additionally:
  - Field shaping rings and DFO tests - 2 version
  - Developmental model CCO tests
  - Grading with Pearl Harbor version of solid NELC rain shield

Gap tests extended to include
    Ball-ring each tier
    Ball to rain shield, each tier
Corona inception dry, on various hardware items, tier-by-tier, as well as entire stack
Ultrasonic fault detection
Thermister heat rise tests
Inferior visual inspection vs boroscope, BIA cold
Pressurization with
    N_2 SF_6
Sealing of grout or joints by various means
Grading tested post insulation on platform-mounted motor generator set

<u>3rd LLL Tests NELC</u> 03 - 27 Oct 1972

Glass brick wall test section
    DFO/WFO
    DWS/WWS
    DCI/WCI
    Grading
    Durability
    Grading chngs of BIA if any in presence of wall and roof 60° and 180°
Further sealant tests, using casting resin
Further protective gap tests
Heat rise measurements on East tower #2
Calibration of base current meter to explore reason for
    "frequency" effect, on Wheeler donut
    Design and installation of new
    Pearson/Fluke digital meter system
Interior inspection via boroscope, BIA action

<u>2nd Series Chollas Heights Tests</u> NEL model range 28 Sept 1972
Chollas 3 - 10 Nov 1972

Lapp BIA ½ scale grading with and without extended rain shield
    Q-meter
    Ball gap
Glass brick tests
Omega BIA on pedestal and off pedestal

<u>4th LLL Tests - HV Facility using Oil Capacitors</u> 26 Jan- 03 Mar 1973

Omega BIA
    On base plate
        No rings
        Grading ring
        Rain shield
    On small pedestal as above
    On high pedestal (Annapolis as above, +:
        Raise rain shield
        With and without base ring
        Dry and wet grading

Capacitor breakdown tests
- Rough fill
- Quiet fill
- Quiet fill + degas
- Quiet fill + degas and settling

Oil tests
- 60 Hz with/without separator in cup
- VLF
- DC

<u>3rd Chollas Heights Tests</u> March-April 1973

Omega BIA model on pedestal
Test for tuning capacitor models

<u>4th Series Chollas Heights</u> June-July 1973

Final modelling Test Facility, 30/1
Post-insulator grading, electrolytic tank

<u>500 kV Test Facility, NELC at LLL, construction</u> 13 Sept-20 Oct 1973

<u>HV Tests Omega BIA, I.U., Lapp BIA, Lapp Porcelain Mods</u>
31 Oct-22 Nov 1973

Omega BIA
- DFO/WFO, DWS/WWS, DCI/WCI
- As-built 01-09 Nov
- As-built "
- Manure test
- On pedestal, no bottom ring
- On pedestal, with bottom ring
- Calibrate gap
- Ice test
- Salt water test

I.U. test, as-built, in conj with Omega BIA
- DFO, WFO, DCI, WCI, Grading 17-19 Nov 1973
- Internal arc and inspection

I.U. test, with 1st modification - 4" ring dropped 2' 1-2 Dec 1973
- with 2nd modification - thick ring - later in year

Omega BIA test, raised rain shield
- DFO, WFO, DCI, WCI, Grading 2 Dec 1973

Omega BIA test, raised rain shield with spring collars

Lapp BIA
- Construction, 3-5 Dec - original rain shield
- Baseline test with NELC extended rain shield 5-8 Dec 1973
  - DFO, WFO, DCI, WCI

CEMCO BIA mock-up original form ABC 60 Hz 9-16 Dec 1973

Clyde Richards crockery tests, with added petticoats
9-10 Dec 1973

Lapp BIA tests, with NELC rain shield and C.R. field-shaping ring 17-21 Dec 1973

HV Tests, Omega BIA, I.U., Lapp BIA, CEMCO BIA, Gaps

Rubber petticoats and field shaping rings 30 Jan-4 Feb 1974

Lapp BIA - zipper failure

Gap tests

Stinger ball - Westinghouse single gap 4-7 Jan 1974

Smooth ball wet and dry

Zipper failure 10-11 Jan 1974

With dirt

CEMCO BIA

DFO, WFO, DWS, WWS, WCI, DCI - no gaps 14-17 Jan 1974

Sphere gap test

Horn gap test 17 Jan 1974

Inverted top rain shield 17 Jan 1974

Inverted top rain shield - raised high 18 Jan 1974

Sphere to "cylindrical stinger" gap

Sphere to sticker ball

Stinger to rain shield, normal position 19 Jan 1974

Thicker added outer ring

Sphere to stinger

Heat run

Manure test 22 Jan 1974

Ice and snow, salt water 23 Jan 1974

More inverted rain shield 29 Jan 1974

Lapp I.U. 3-tier 2 Feb-6 Feb

Mods 1 through 12

DFO, WFO, DCI, WCI, Grading
(1, 2, 4, 5, 6, 8, 10, 11, 12)

Mods 13-19 26 Feb-3 Mar 1974

Omega guy strain insulator

Q-9-B pentapost

Stock - no anti-corona hardware 08-09 Feb 1974

Mod 1 - saddles 11 Feb 1974

Mod 2 - saddles and rings 11 Feb 1974

Q-9-A pentapost center post only

Stock 12 Feb 1974

Mod 2 12 Feb 1974

Mod 4 - saddles, rings and collars and stirrups 15-27 Feb 1974

BIA mock-up 20-22 Mar 1974

Mod 2 27-28 Mar 1974

Lapp I.U. 3-tier	
Mods 15, 18, 19, 20, 21	2-5 Apr 1974
2-tier	
Mod 2 2" upper rings	5 Apr 1974
Bottom rings	
Mod 3 same as Mod 21, 3-tier	6-8 Apr 1974
CEMCO Hardware and ball - rod gap	
Gaps DFO, WFO, WWS, DWS, D/WCI	25-27 Apr 1974
Top anti-corona hardware development using modified top rain shield	27-29 Apr 1974
Same but open strut rings and small rain shield	01-04 May 1974
Kotter gaps	05-12 May 1974
Ball - rain shield	
Rod plane, multiple gap	
Hemi-sphere	
Grading of strings	
Sphere sphere	05-13 May 1974
Multiple gap	14-15 May 1974
Kotter gaps single unit, rod-plane	16 May 1974
Rod, rod	17 May 1974
Square single rod-plane	18 May 1974
Quadrapost Q-7 A	19 May 1974
Kotter gaps - square rod	20 May 1974
Sphere-plane	
Cascaded 2 sphere	21 May 1974
sphere-rod	
sphere-sphere	
CEMCO BIA and proof test	20-27 July 1974
DFO, WFO, DWS, WWS, DLI, WCI	
Heat rise, etc.	
Lapp Saddle Post Guy	30-31 July 1974
Tower Jacking West	1-5 Aug 1974
BIA #2	06-19 Aug 1974
Gap calibration	10 Aug 1974
Q 7A tests, stock	12 Aug 1974
with fixes	
BIA 2 fixes for corona	17 Aug 1974
Q 7	19 Aug 1974
Rod-plane gap, grading ring with central free standing insulator	22-27 Aug 1974
Rod wet	
Spiral rod, rod, gap	
Marker ball test	29 Aug 1974
Graded rod-plane gap tests	03-04 Sept 1974
BIA #3	15-17 Oct 1974

Vibration damper and Phyllistran tests	20-28 Oct 1974
Marker ball tests	
Capacitor failure and filling tests, Annapolis	30 Jan-11 Mar 1975
Impulse tests, MGD, Patuxent River	20 Mar-10 Apr 1975
Capacitor at Annapolis	August and September
DECCA Austin Insulator I.T. 001 tests	15 Oct-24 Nov 1975
Gaps calibration, ext. heat run	1975
Grading, tests and adjustment of top ring	
I.T. 002, 3, 4, 5 Qualification tests	9-24 March 1976
CEL new organic insulator tests	25 Mar 1976
(comparison with Lapp compression post)	10 Apr 1976
Small Lapp compression post	DFO, DWS, DCI
Stock	WFO, WWS, WCI
With "fat" shrouds in arms	
La Moure oil-filled insulator fiberglass	
Stock rings	DFO, WS, CI
With collars and stock ring - brine	
With collars modified rings	
High power hardware (Argentine)	
Oil-filled fiberglass, Bullers Ceramic	
4-Section glass Lapp, no protectors	
12-Section glass Lapp, with La Moure rings	
4-Section Josselyn, flexi-coupling, ceramic, no protection	
12-Section Josselyn, flexi-coupling, ceramic, no protection	
No rings	
La Moure rings	
O.B. Fiberglass rod	
O.B. Fiberglass rod, with cast petticoats	
Permali aliphatic resin, fiberglass rod	
No protection	D/W FO, WS, CI
With LaMoure modified rings and brine and mud	
Cervit Block	
MD Final VLF Tests	11-13 April 1976

18.3 Table 3

Insulator Travel History

	1972		
05	09 - 12	1st Ad Hoc Committee meeting, possible NAA and NPM causes, plan of action at LLL	Wash., D.C.
	21 - 29	NOSC 1st LLL tests, East Tower - gaps, grading, voltage NRTF LLL	
06	05 - 08	2nd Ad Hoc Committee meeting, report results of test plan	Wash., D.C.
	19 - 20	Tests at Chollas Heights, NELC,	
07	05 - 28	Chollas Heights BIA and gap Cerelap tests at NELC	San Diego, CA
08	13 - 21	2nd LLL test, East and West Towers, gaps, grading, voltage, NRTF LLL DECO/Chesdiv	
08	24	Design Review, H & N, Los Angeles	
08 09	20 - 31 01 - 09	3rd Ad Hoc Committee meeting, Omega insulator problems, BIA design and preparation and proposed specification	Wash., D.C.
10	03 - 27	3rd LLL test, East Tower, gaps, grading, glass brick wall	NRTF LLL
11	03 - 10	Model tests at Chollas Heights	
11	14 - 25	BIA specification writing, Omega guy strain insulators, HV test design	Wash., D.C.
12	12 - 14	NSS Tower inspection, HV test bed using gaps, finalize design	Wash., D.C.
	1973		
01	04 - 05	Omega BIA test plan, HV facility discussions	Wash., D.C.
01 03	26 03	BIA grading, capacitor and gap tests	LLL
04	02 - 22 22 - 24	BIA bid evaluation and capacitor post mortem Wash., D.C. BIA HV test procedures and bushing availability, Boston	

<u>1973</u>

05	07 - 17	New 500 kV test facility construction preliminary LLL	
06	11 - 14	BIA bid review, first step	Wash., D.C.
07	05 - 06	BIA final specification	Wash., D.C.
	07 - 13	HV facility design review	Wash., D.C.
08	15	BIA Design Review	Wash., D.C.
08	20 - 31	BIA Test facility Design Review	Wash., D.C.
09 10	13 21	LLL HV test facility construction " " "	LLL
10 10 11	23 31 20	LLL HV test facility proof, I.U. tests Omega BIA	LLL

<u>1973 - 74</u>

	11	28	Omega BIA, petticoat (Clyde Richards) IT tests	
	12	09	Lapp BIA tests NRTF LLL	
	12	09 - 16	60 Hz Continental BIA mockup tests A.B. Chance, Mo.	
73 74	12 02	16/23 20/24	Lapp BIA, Continental BIA mock-up, Omega guy strain gap tests, Continental BIA NRTF LLL	
	(01 02	26, 01)	Design Review	Wash., D.C.
	03	04 - 06	BIA Design Review	Dallas, Texas
	04 05	24 23	Continental BIA hardware development	LLL
	05	29 - 31	BIA Design Review	Dallas, Texas
	06	09 - 13	BIA inspection	Annapolis
	07 09	18 06	Development tests, gaps, BIA qualification, LLL tower	
	09	20 - 25	Steering Council	Wash., D.C.

1973 - 1974

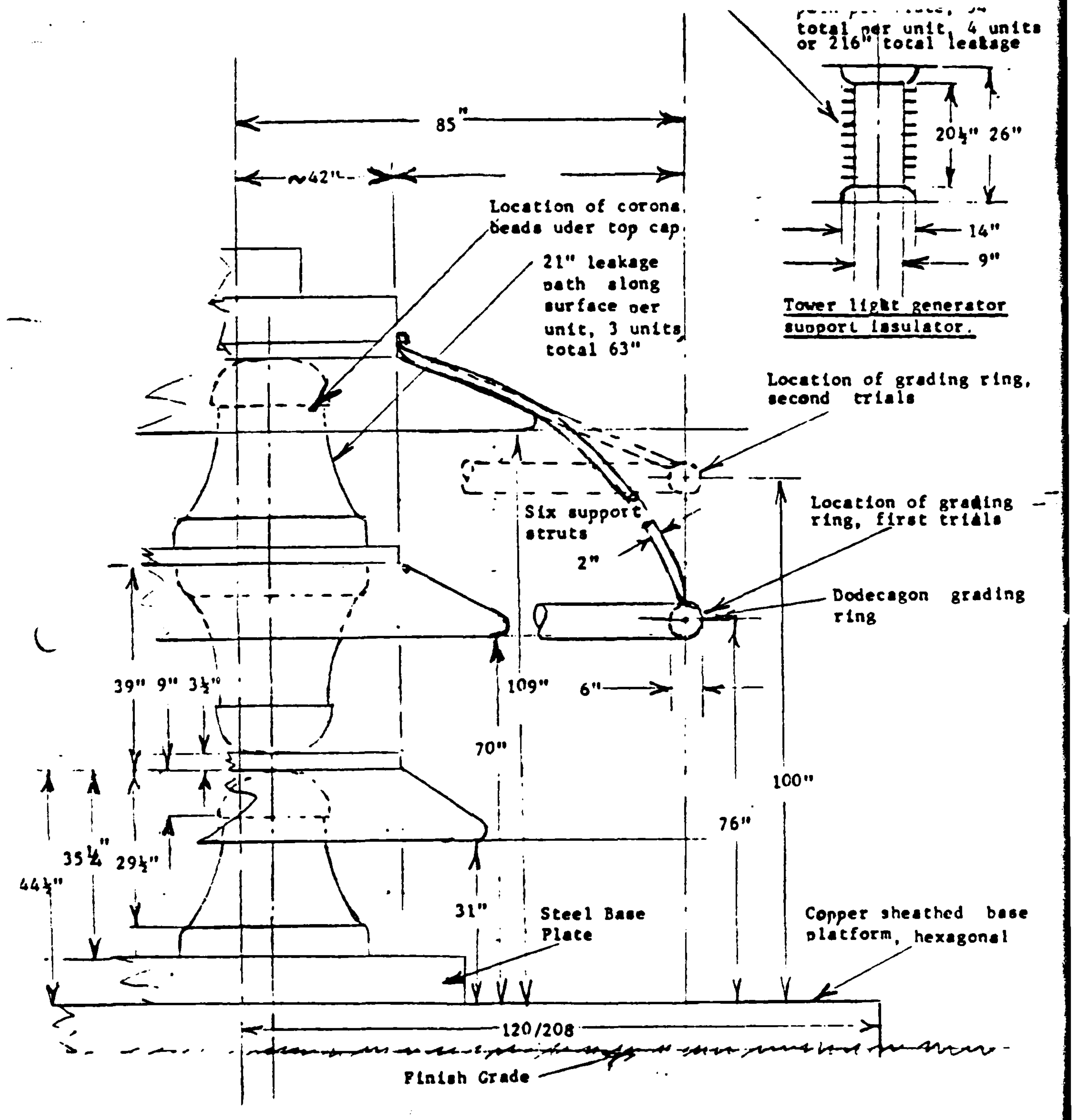
10	11 - 25	BIA #3 insulator tests Omega and Phyllistran; Haiku markers	LLL
11	10 - 17	Haiku span inspection	Kaneohe, Oahu, Hawaii
11	26	Omega span post mortem	LAX
12	11 - 13	I.T. Design Review	Toronto

1975 - 1976

	03	20	Patuxent River impulse tests	Wash. and NATC, Patuxent
	04	20		
	05	01 - 09	Insulator workshop conference, NSF	Wash., D.C.
	10	14	I.T. test, gap tests, Omega insulator tests	LLL
1975	11	24	001	
1976	03	09	I.T. tests 002, 003, 004, 005 CEL insulator tests	LLL
	04	14		

Figure Titles

1. Original Lapp BIA for NSS and NPM and NELC Grading Ring
2. Omega BIA
3. Pendapost Insulator for 1200-foot Omega Tower
4. Glass Brick Wall Concept, and NELC Extended Rain Shield
5. West Elevation of Capacitor Bank Test Facility at Lualualei
6. Plan View of Capacitor Bank and Test Insulator Installation
7. 500 kV NELC Test Facility Plot Plan, Lualualei
8. 500 kV Test Facility Control and Interlock Schematic
9. 500 kV Test Facility RF Schematic
10. Final NELC Anti-corona Hardware Models for Lapp I.U.
11. Original CEMCO BIA Mock-up with First Revised Gap System
12. First Series CEMCO Single Gaps Tested at 60 Hz and VLF
13. Lapp Saddle Post Insulator with Modifications (Single Unit Serves as Guy Breakup)
14. CEMCO LLL BIA, Final Version
15. Isolation Transformer
16. Dual Post Antenna Guy Strain Insulator - Lapp "Double Triple"
17. CEMCO Top-load Insulator as Modified by NELC



Elevation and approximate dimensions of experimental grading ring used at Lualualei 27 - 29 May, 1972 . Leakage path comparison of main base insulator and support columns for diesel-electric tower light power unit.

Figure 1. Original Lapp BIA for NSS and NPM and NELC Grading Ring

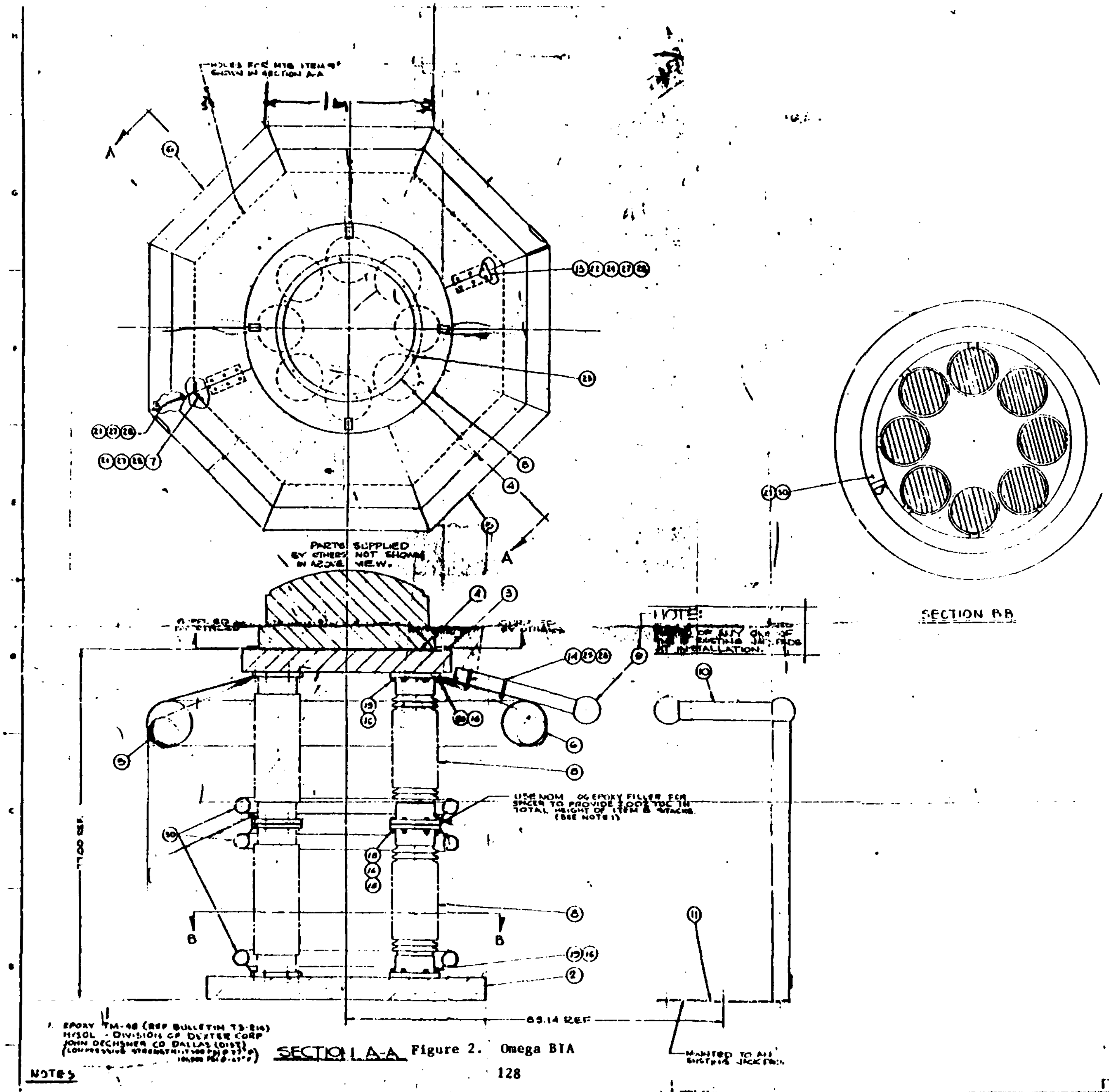
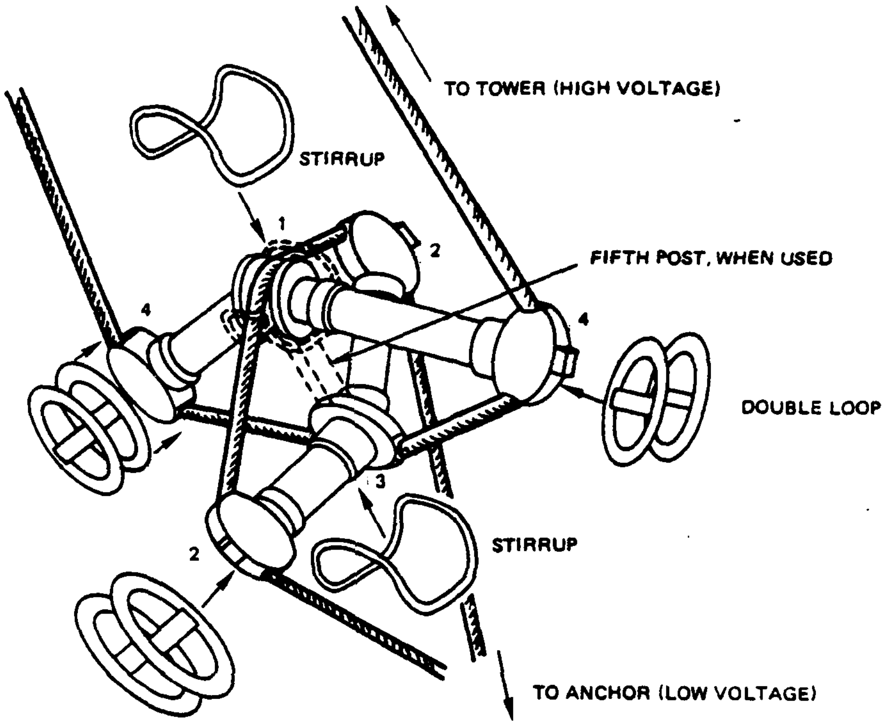
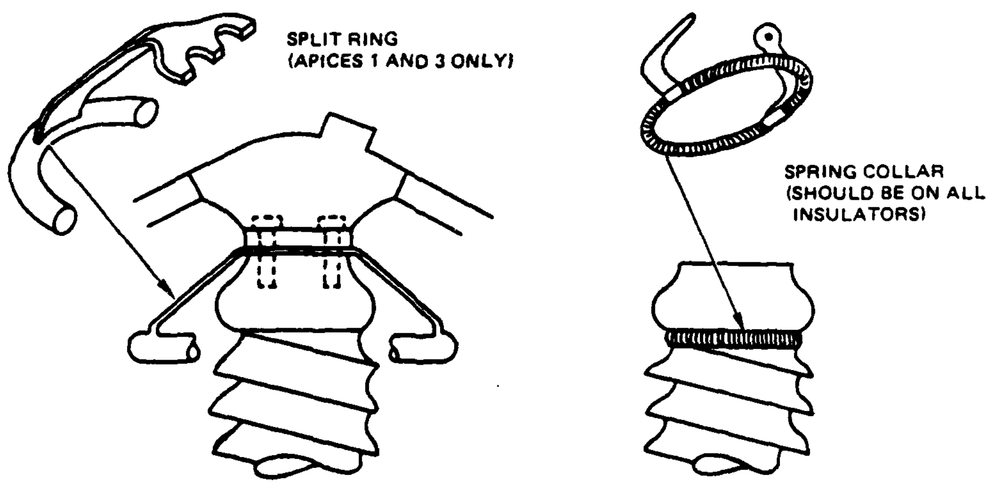


Figure 2. Omega BIA





Anticorona devices.

Figure 3. Pendapost Insulator for 1200-foot Omega Tower

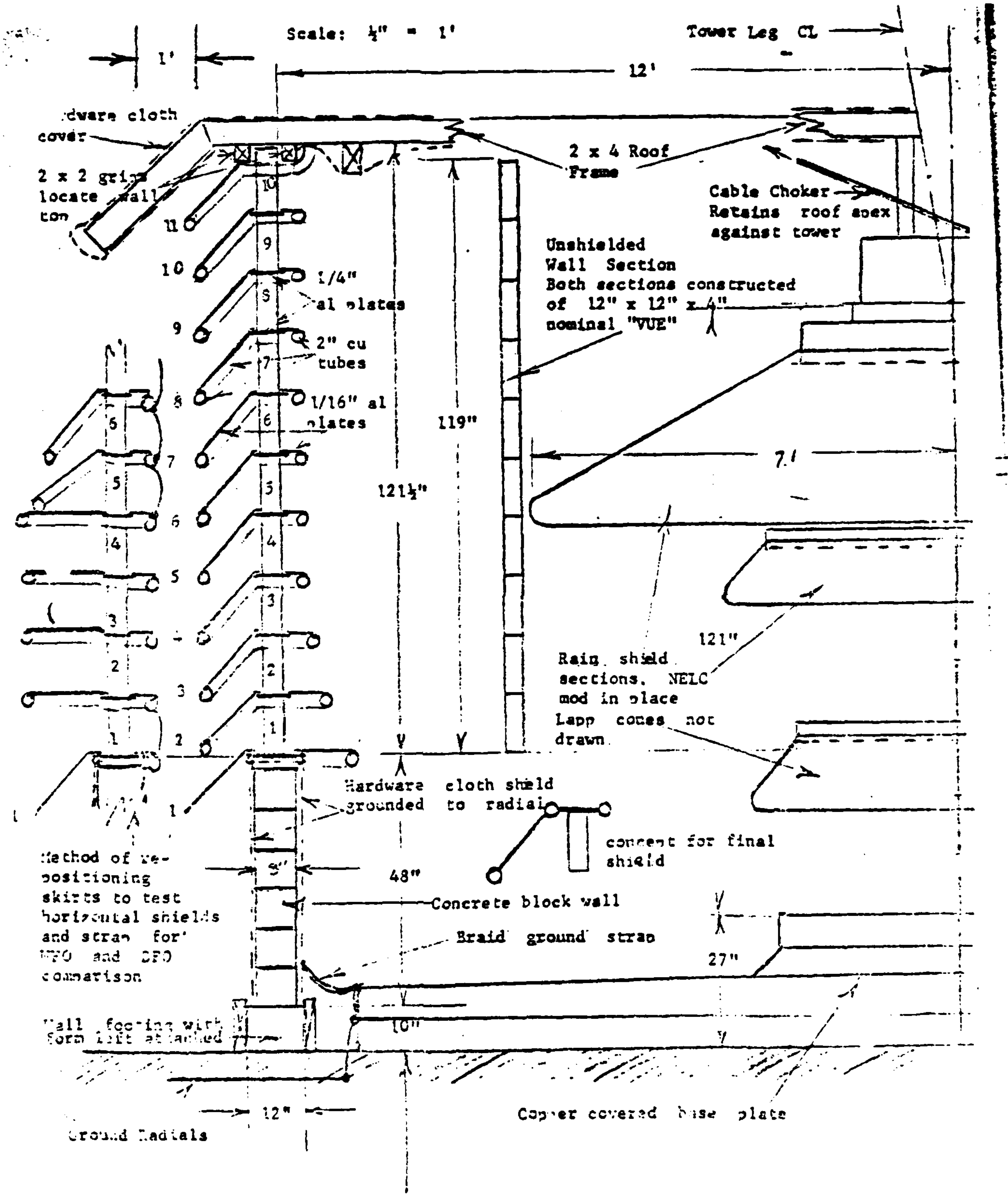


Figure 4. Glass Brick Wall Concept, and NELC Extended Rain Shield

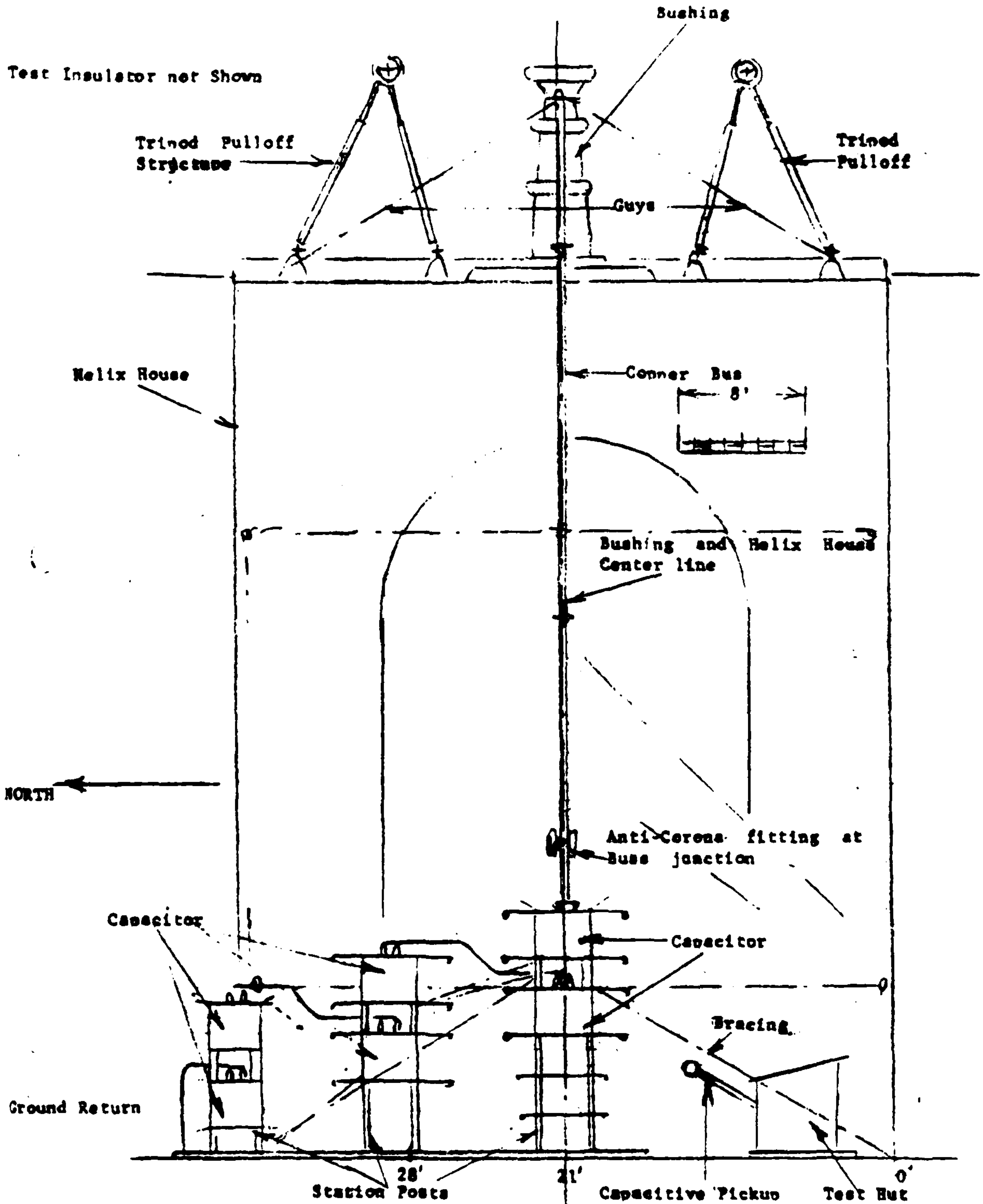


Figure 5. West Elevation of Capacitor Bank Test Facility at Lualualei

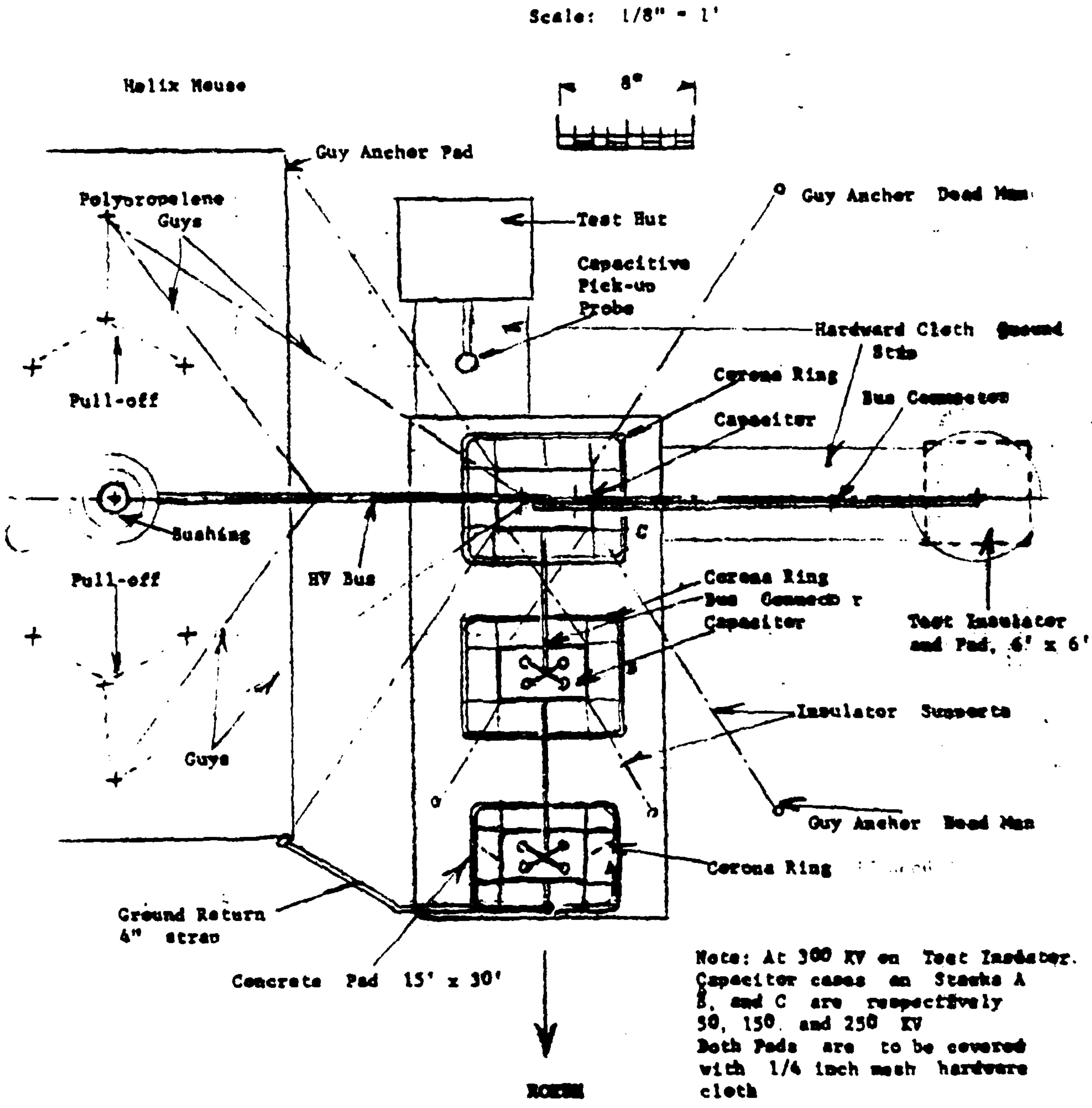


Figure 6. Plan View of Capacitor Bank and
Test Insulator Installation

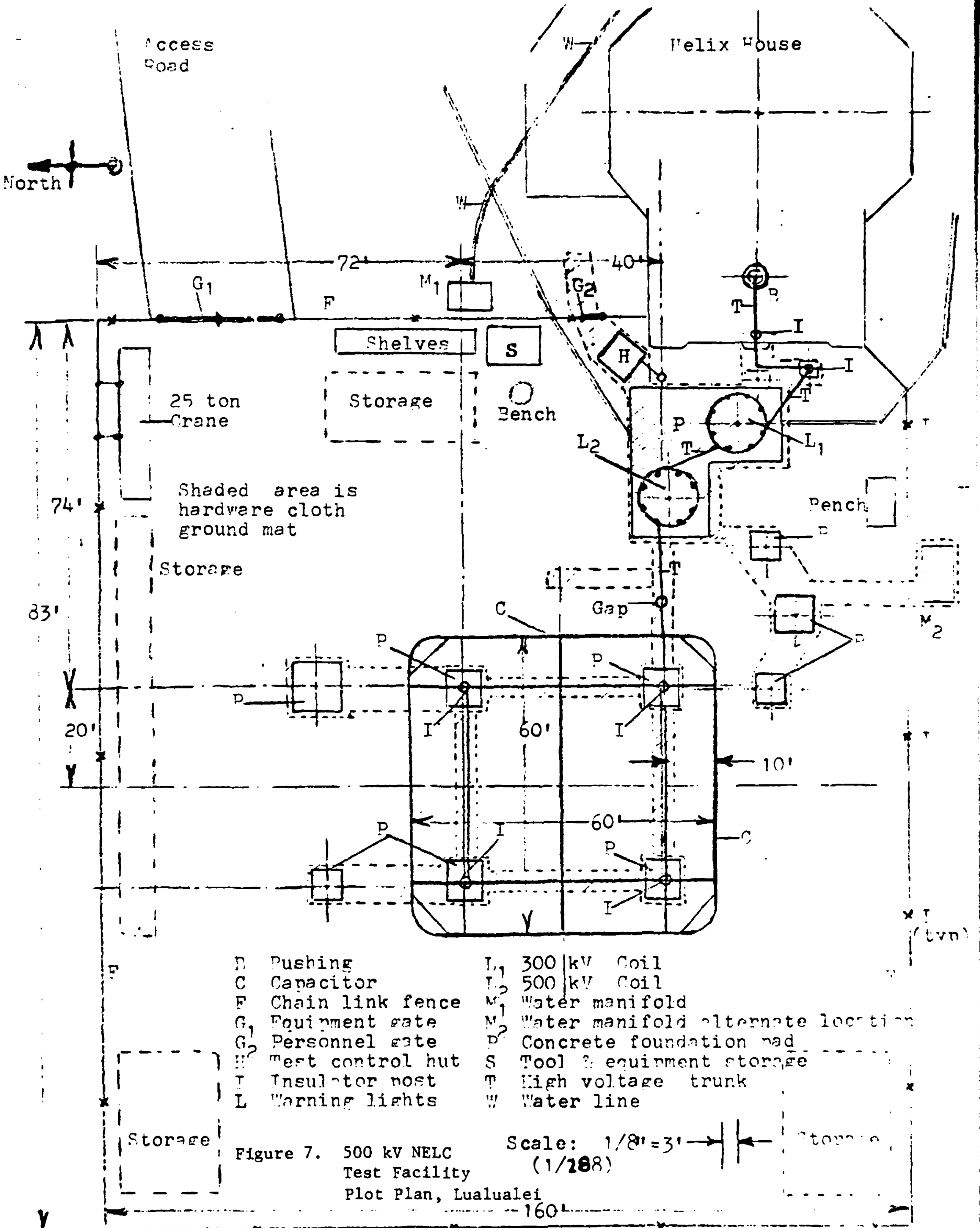


Figure 7. 500 kV NELC Test Facility Plot Plan, Lualualei

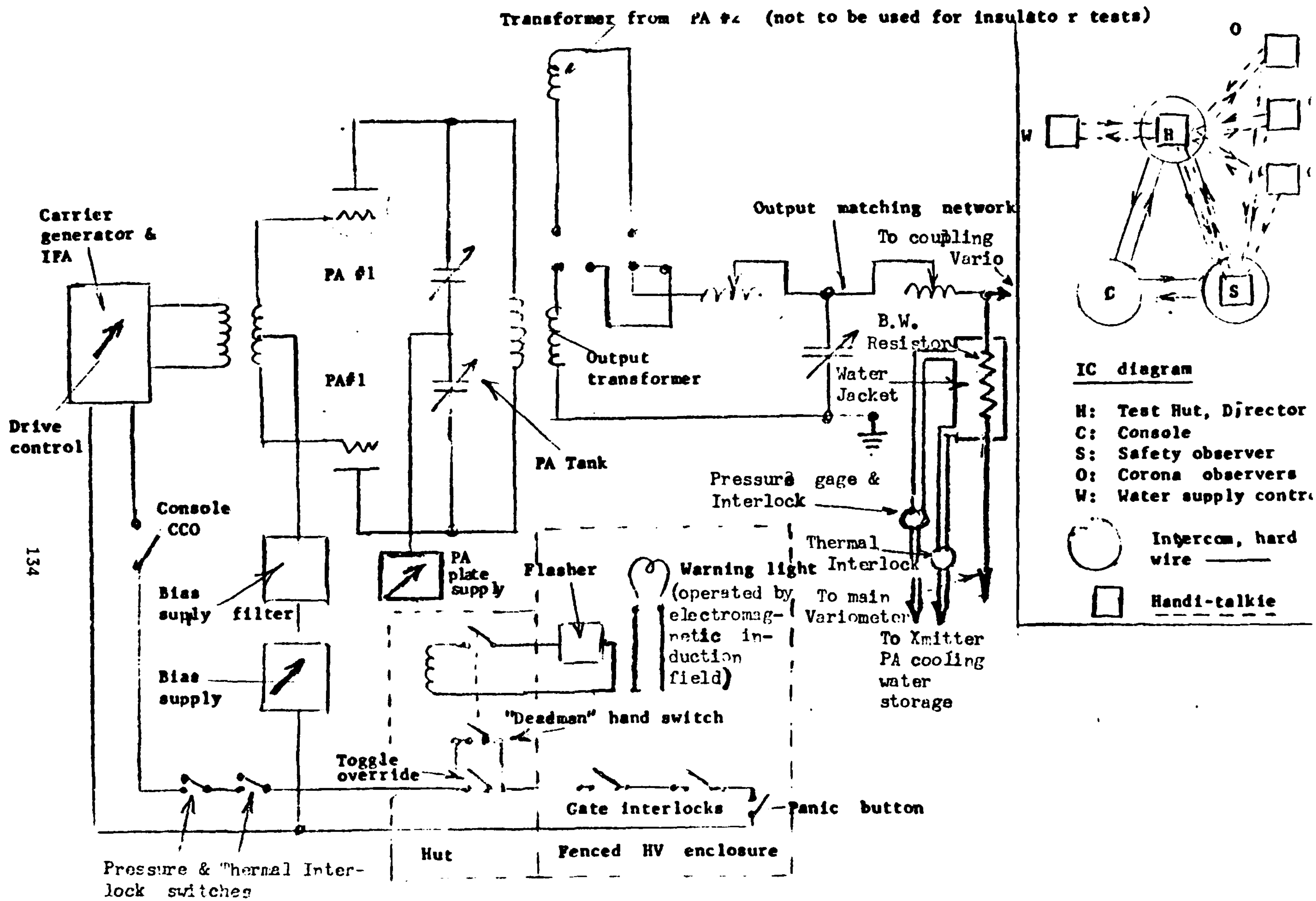
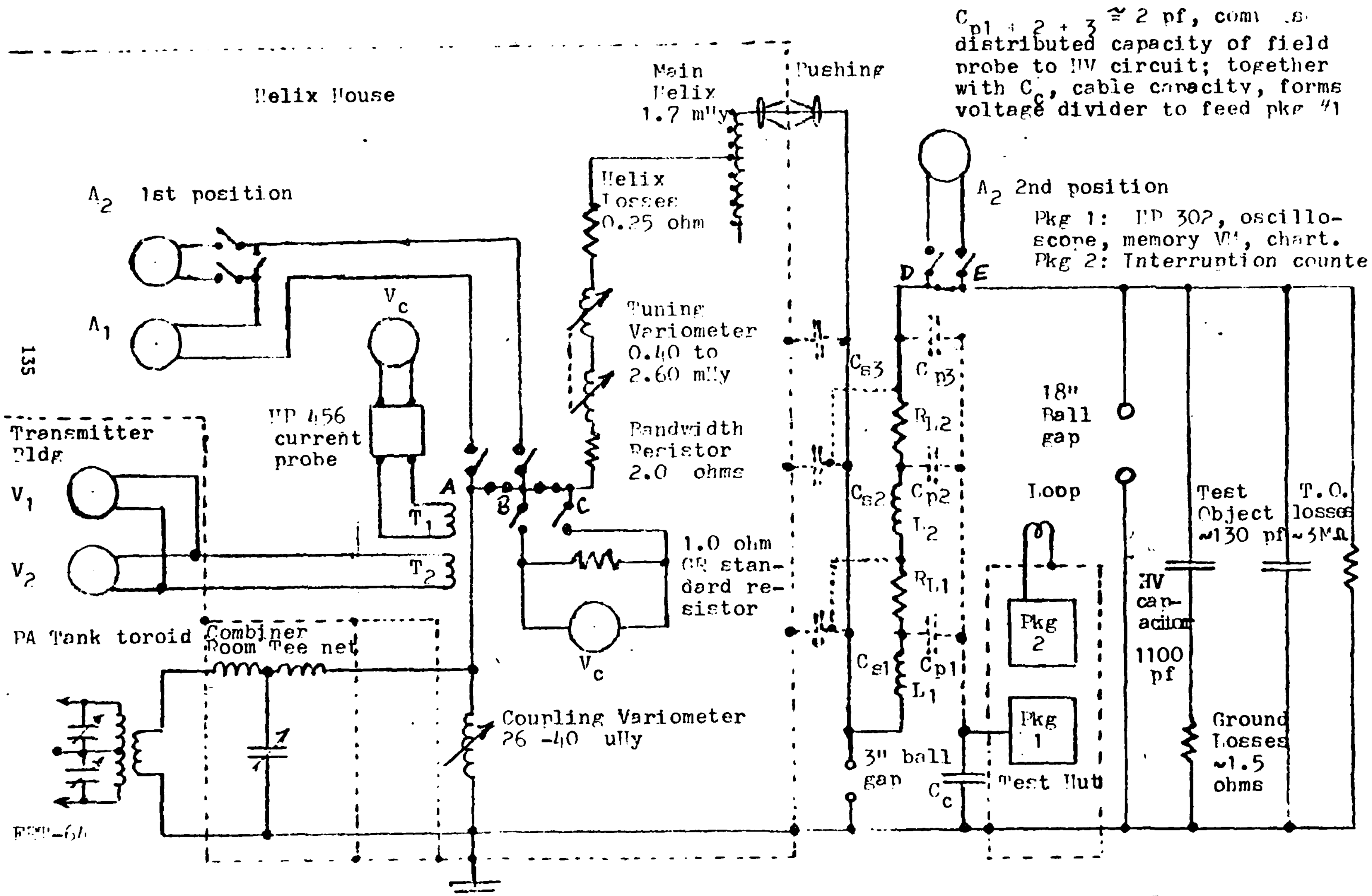


Figure 8. 500 kV Test Facility Control and Interlock Schematic



V_1 Fluke 8300

V_2 HP 302

V_c Any voltmeter to be calibrated

T_1 HP 456 1 amp current transformer

T_2 Pearson current trans.

$A_{1,2}$: 0–8 A RF meters

(These and HP 456 not used in high power operation but are only for calibration)

L_1 = 8.5 mHy, R_{L1} = 0.8 ohm

L_2 = 8.4 mHy, R_{L2} = 0.8 ohm

$C_{s1+2+3} \cong$ 370 pf are stray capacit

Figure 9. 500 kV Test Facility RF Schematic

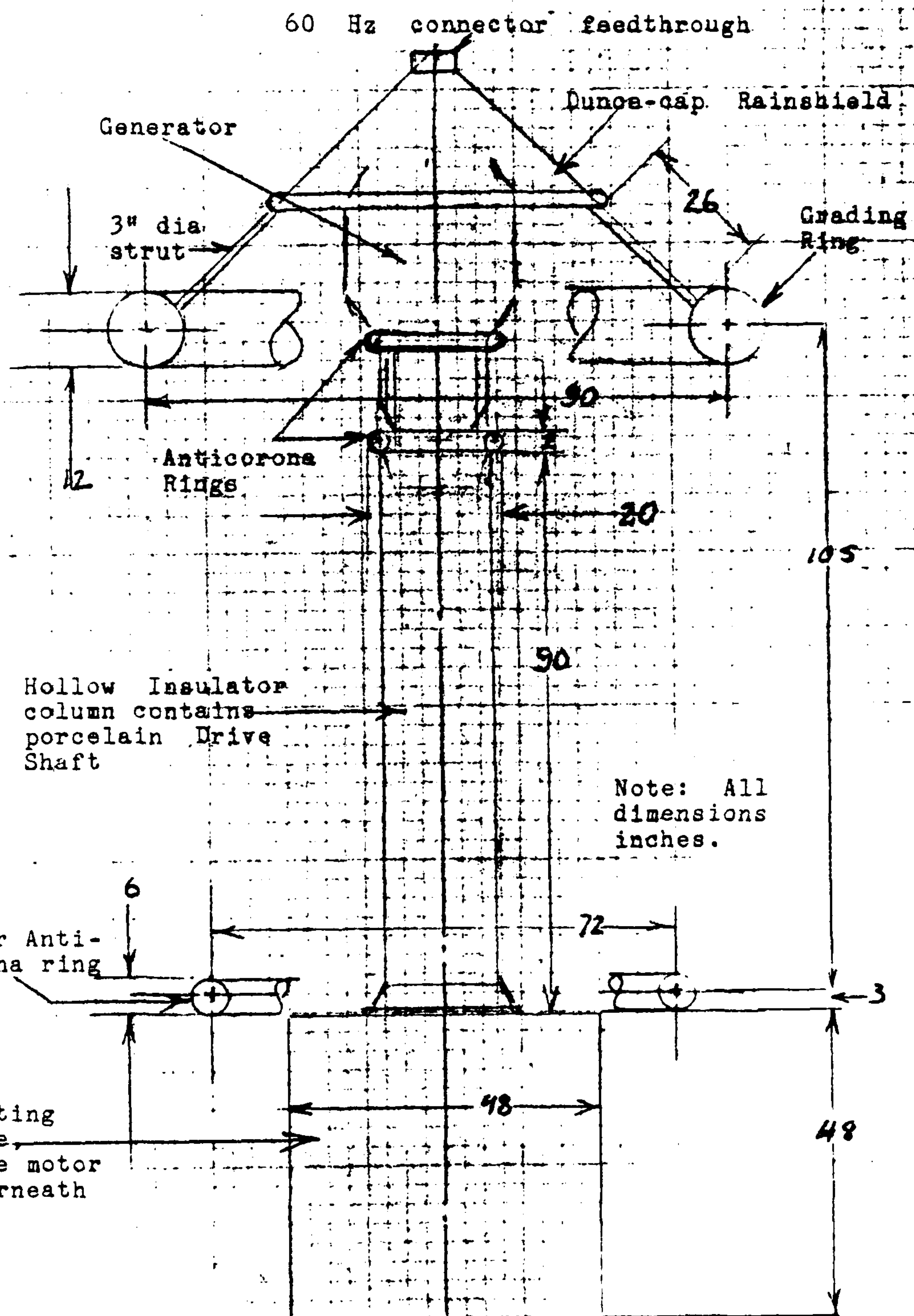


Figure 10. Final NELC Anti-corona Hardware Models for Lapp I.U.

CEMCO BIA MOCKUP and Inflator Gap System Tested at LLL T.F.
24 – 30 Apr 74 and 6-7 May 74

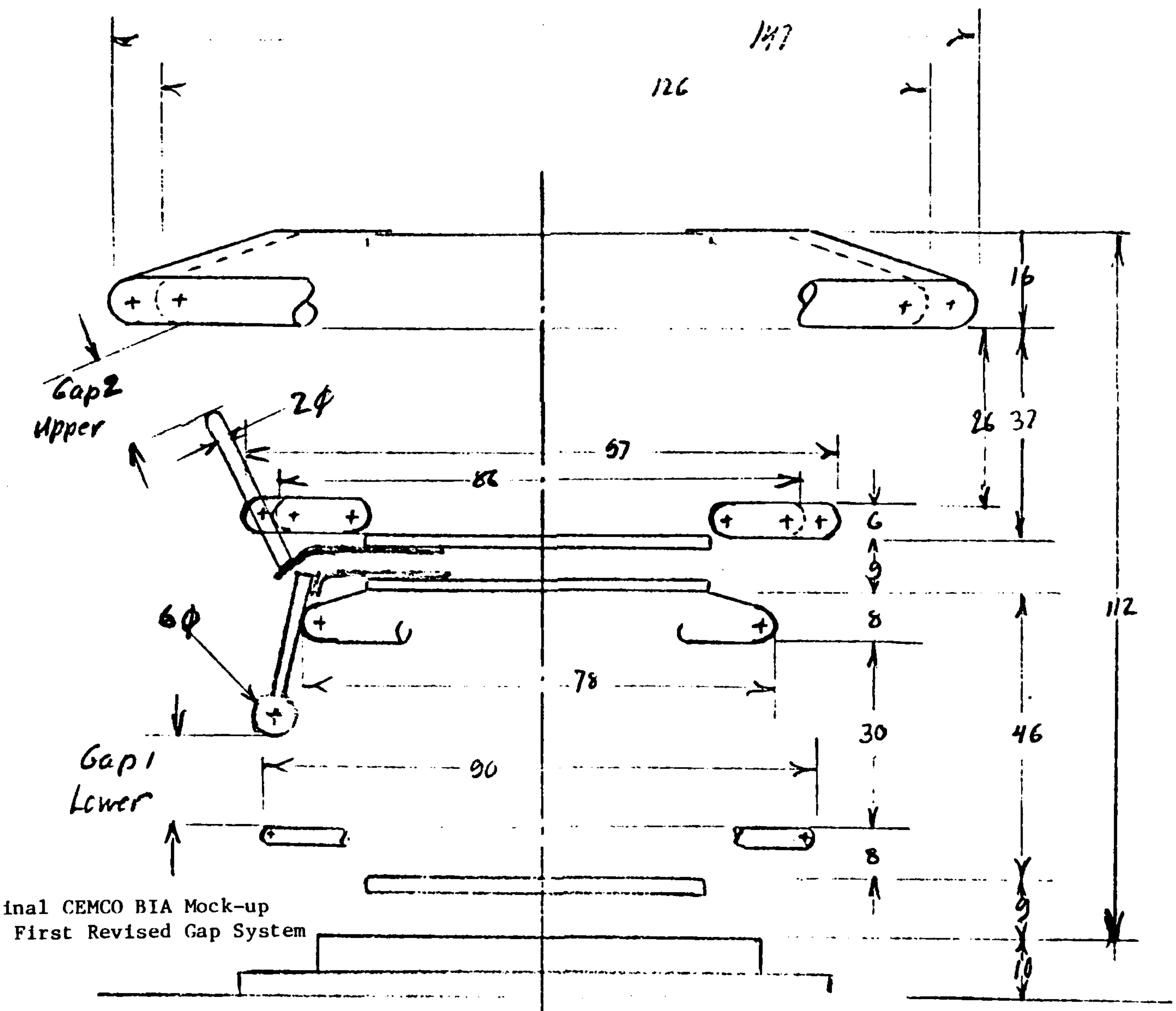


Figure 11. Original CEMCO BIA Mock-up with First Revised Gap System

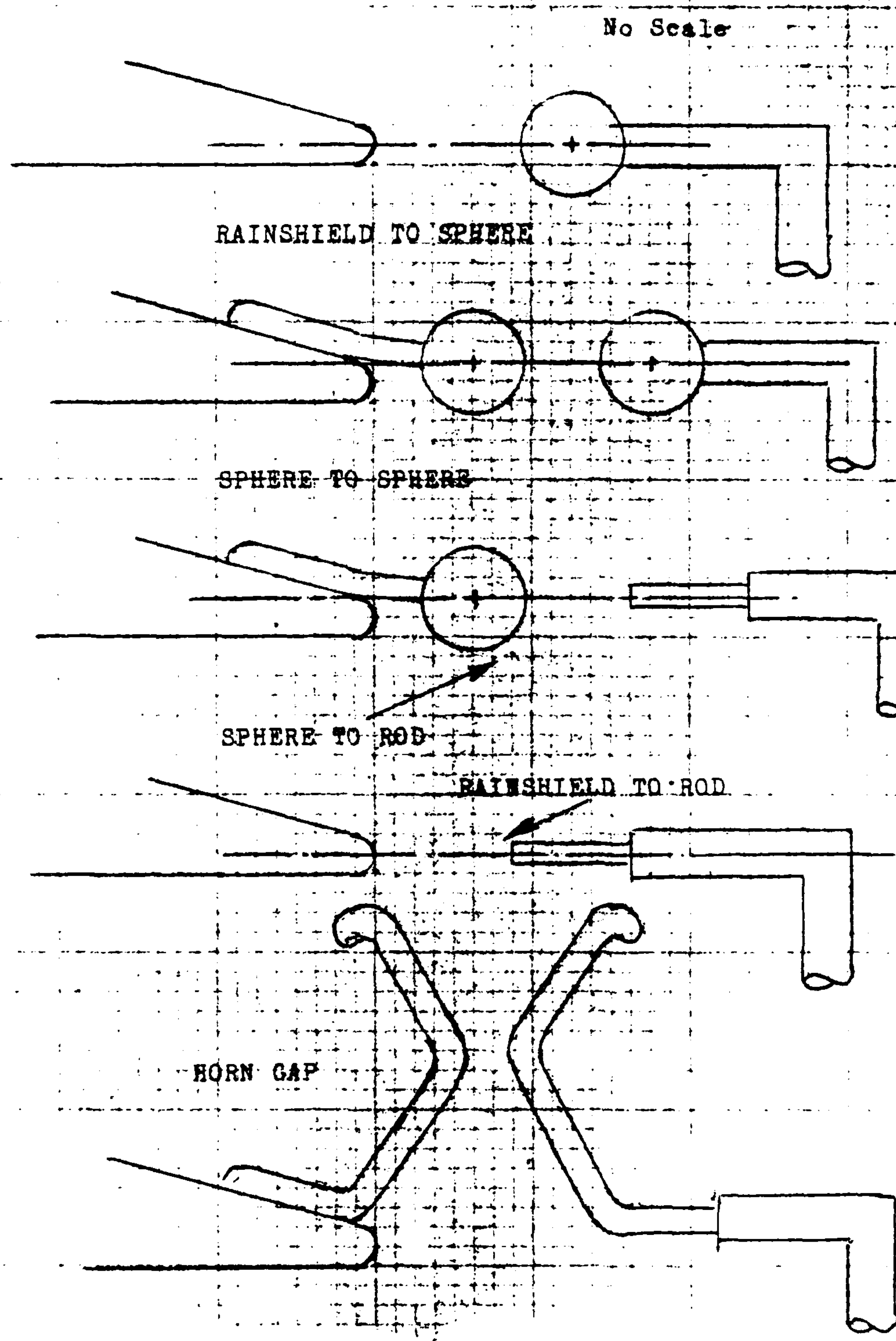
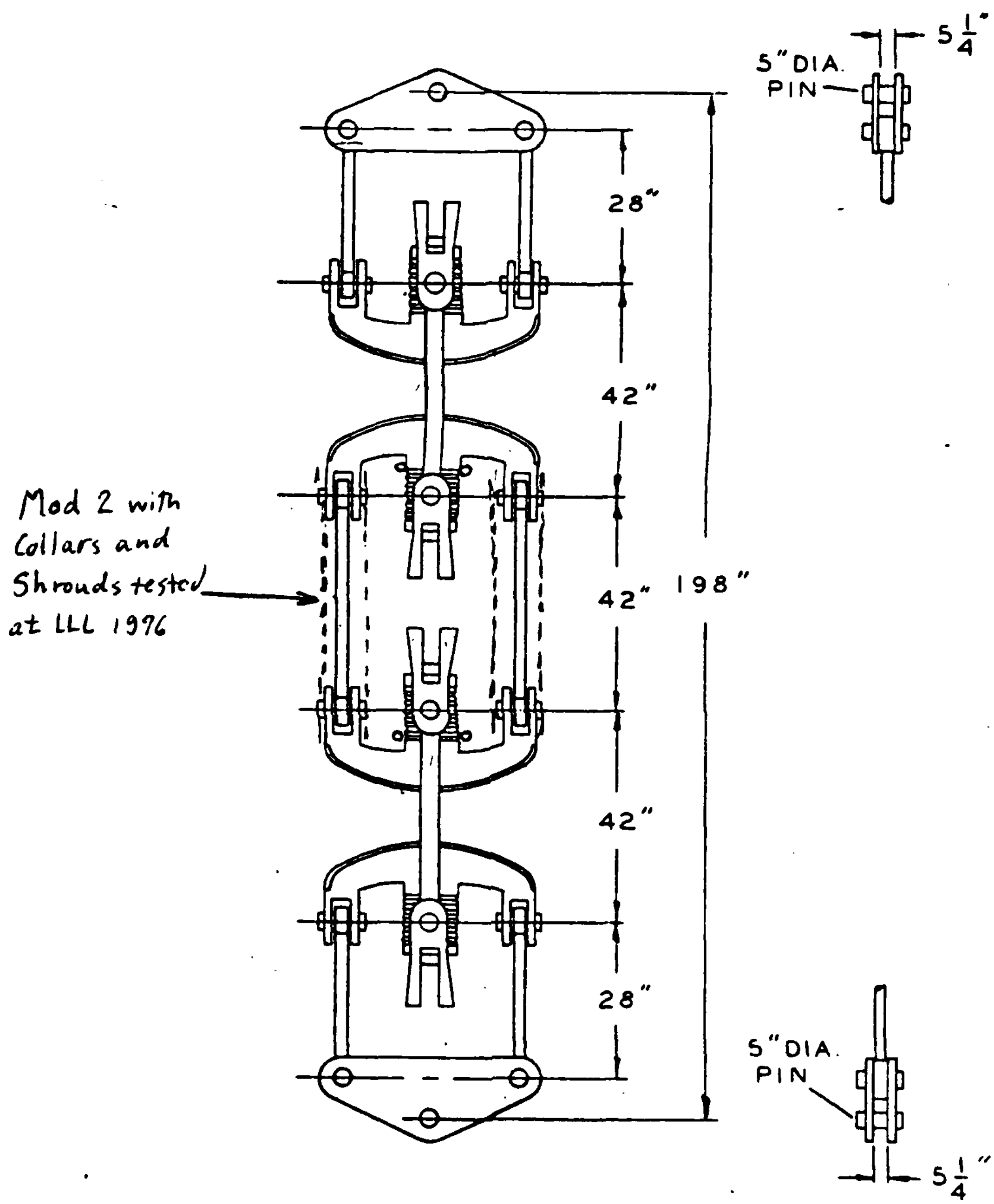


Figure 12. First Series CEMCO Single Gaps Tested at 60 Hz and VLF



ULT. STR. - 620,000 LBS.
EST. WGT. - 950 LBS. PER INSULATOR UNIT
PLUS 500 LBS. FOR 2 YOKES
PLUS 2 LINKS

Figure 13. Lapp Saddle Post Insulator with Modifications (Single Unit Serves as Guy Breakup)

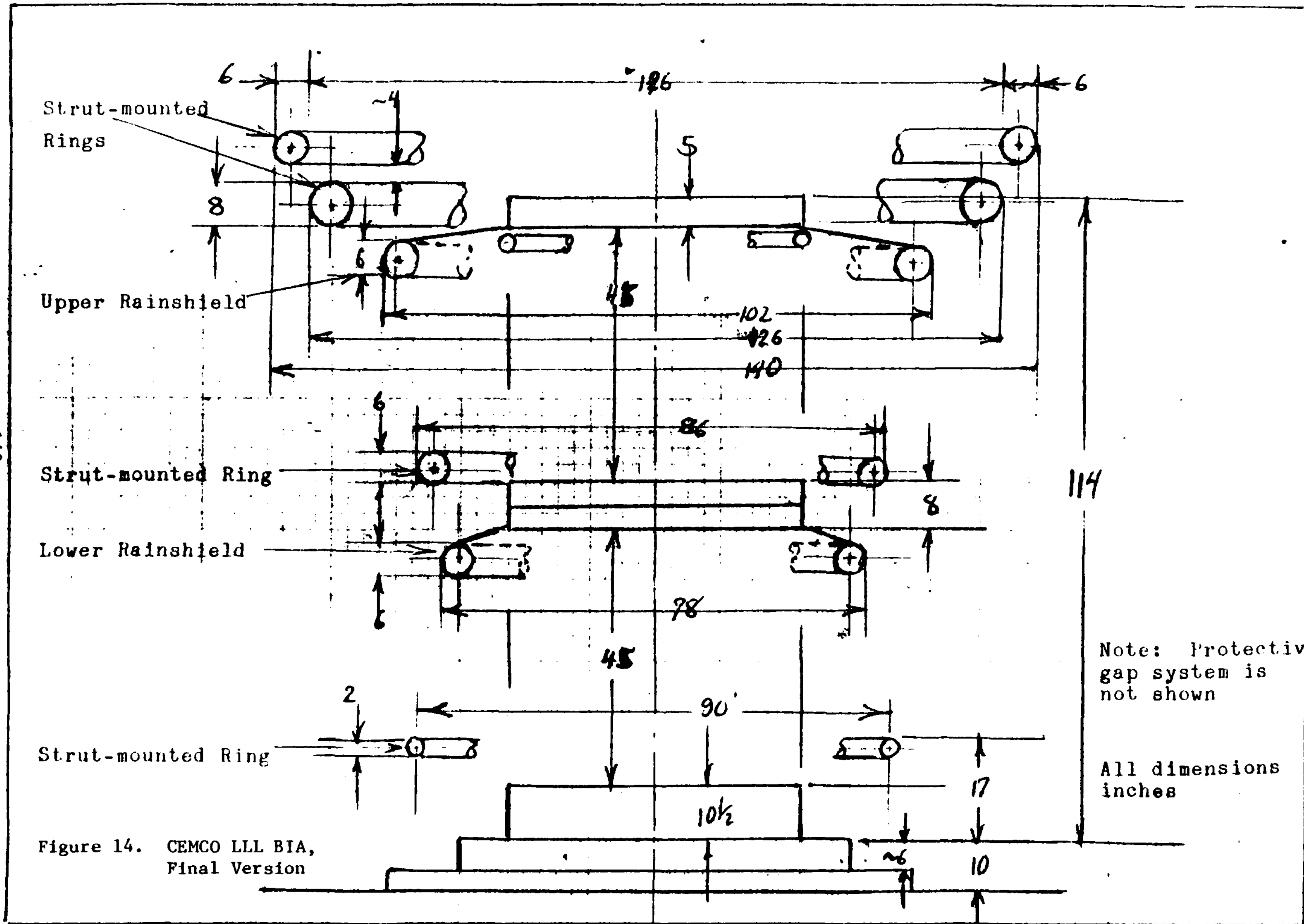


Figure 14. CEMCO LLL BIA, Final Version

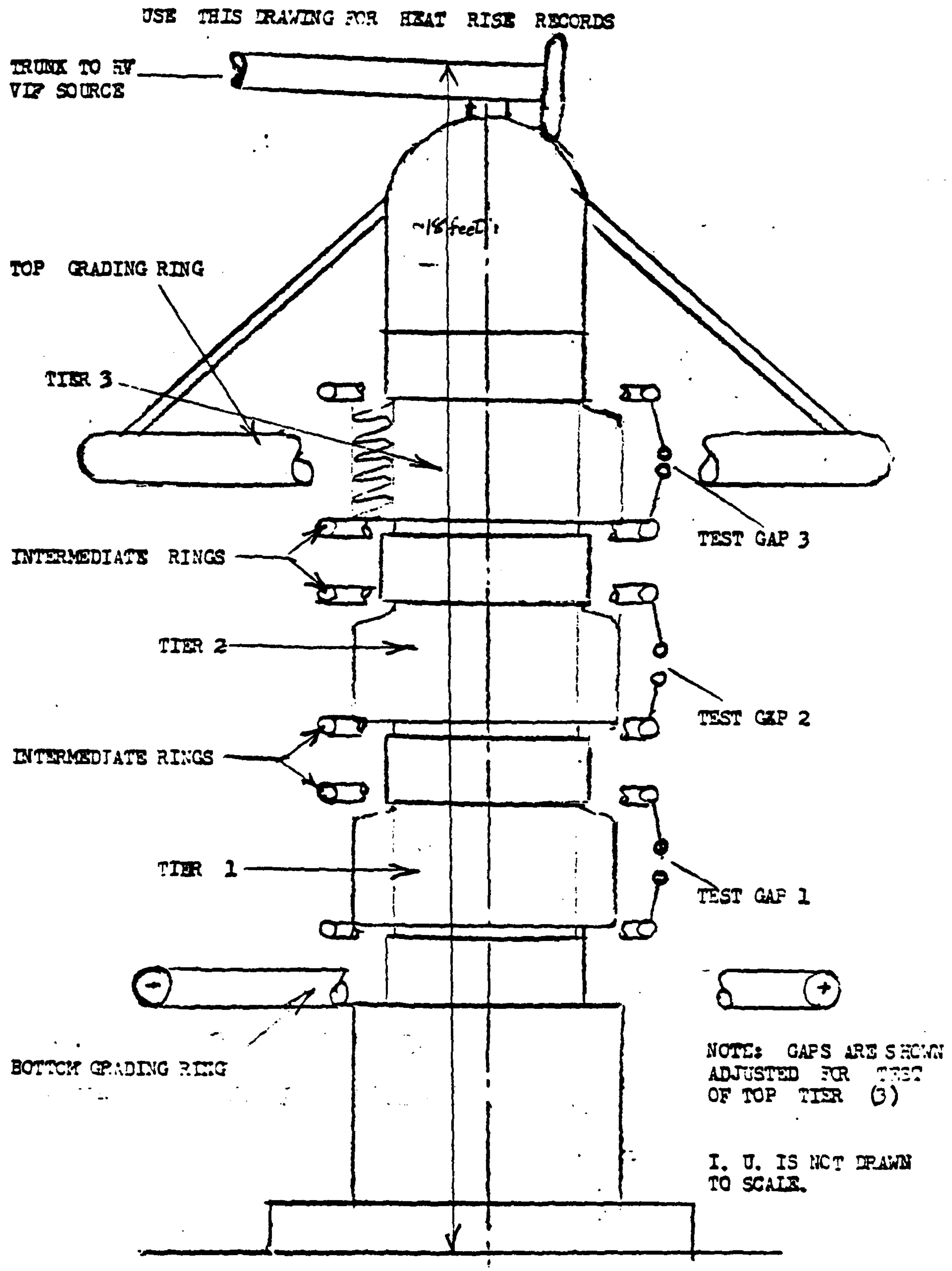
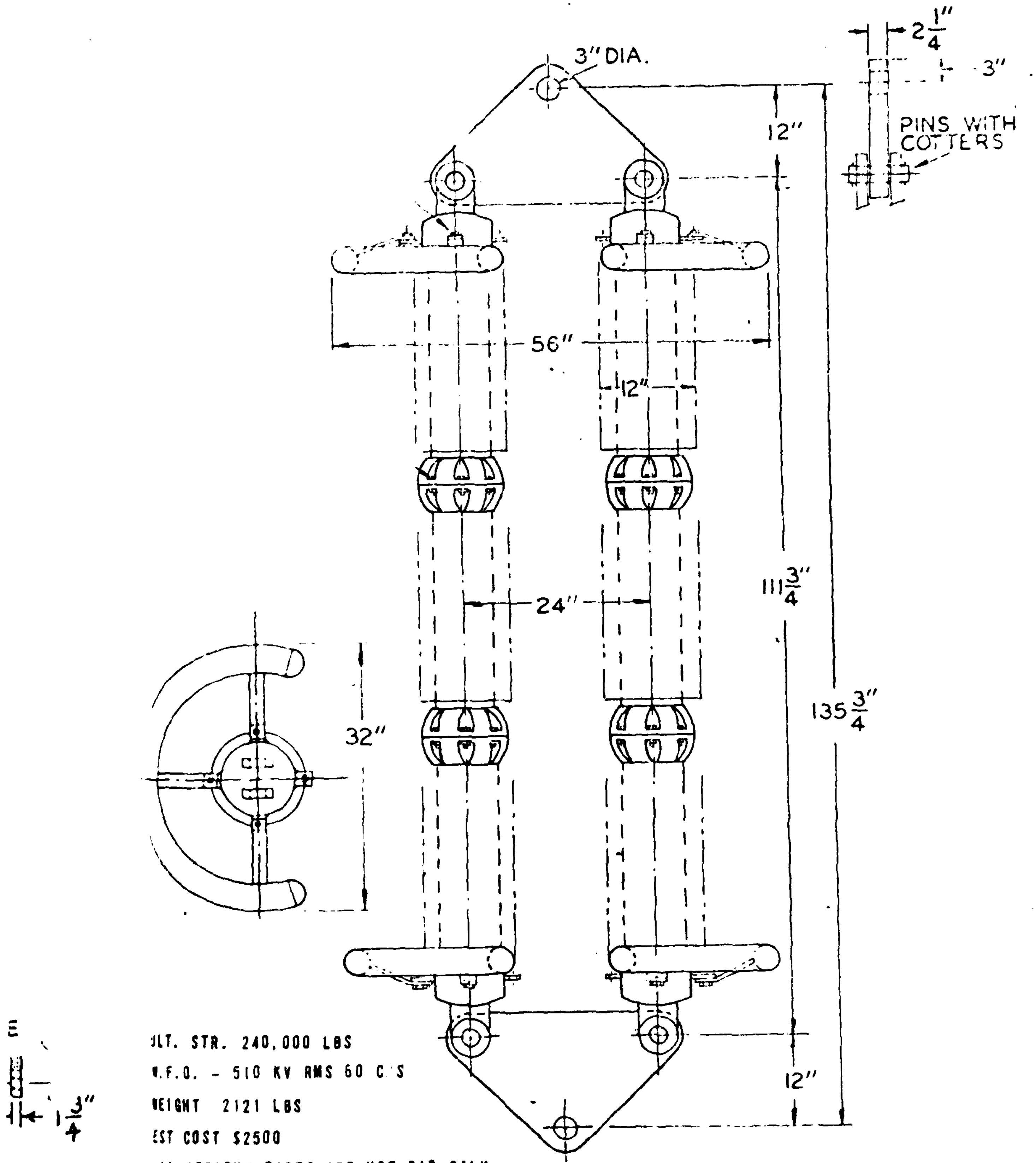


Figure 15. Isolation Transformer



ULT. STR. 240,000 LBS
W.F.O. - 510 KV RMS 60 C/S
WEIGHT 2121 LBS
EST COST $2500
ALL FERROUS PARTS ARE HOT DIP GALV.

Figure 16. Dual Post Antenna Guy Strain Insulator - Lapp "Double Triple"

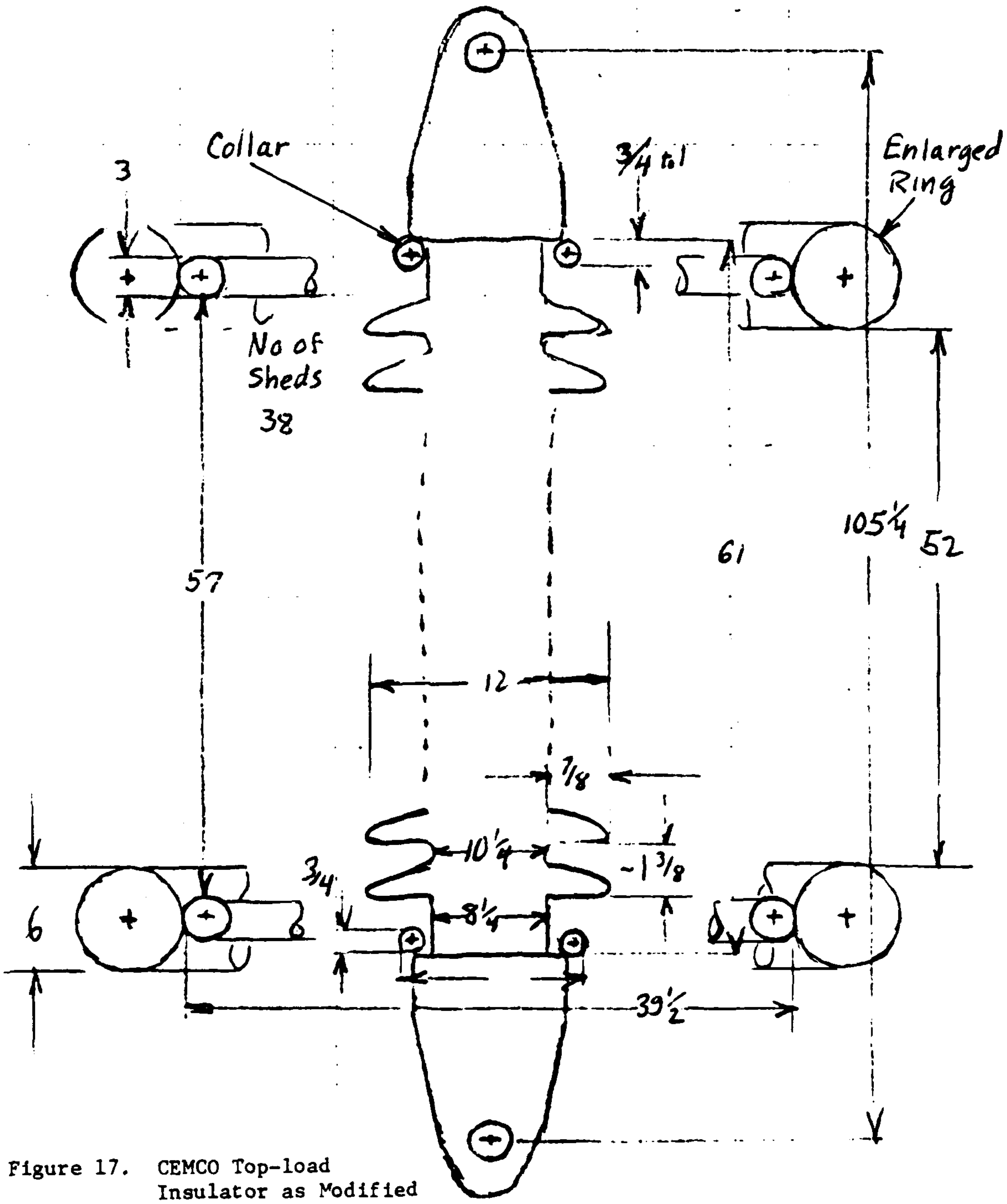


Figure 17. CEMCO Top-load Insulator as Modified by NELC

Dimensions Inches

APPENDIXES

1.	Appendix A:	Early VLF Antenna Insulator Specification
2.	Appendix B:	NELC Letter on Omega Insulator Test Validity
	Appendix B-1:	NELC Memorandum on Tests of La Moure, ND failsafe sets Q4d and Q5d
	Appendix B-2:	NELC Review and Comment on Insulator Ratings and Tests
3.	Appendix C:	NELC Test Plan for LLL
	Appendix C-1:	NBS Test Plan for LLL
4.	Appendix D:	Portions of NELC Letter: Technical Report of VLF Transmitter Antenna Base Insulator Fix Investigation (U)
5.	Appendix E:	Basis for Lualualei High Voltage Test Circuit Design
6.	Appendix F:	NELC Specification: Insulator Assembly, Electrical, VLF Antenna Base (ELEX-I-157)
7.	Appendix G:	Megatek Corporation Final Report: Testing of a Controlled Conductivity Water Source
8.	Appendix H:	Proposed 1973 - 1974 Test Plan and Schedule
9.	Appendix I:	NELC Letter: Supplementary Mock-up Test Plan and Schedule
	Appendix I-1:	NELC Mock-up Test Configuration
10.	Appendix J:	NELC Naval Speedletter: Static Isolation Transformer, Detailed VLF Test Plan
11.	Appendix K:	Multiple Gap Device Test Description
	Appendix K-1:	Megatek Corporation Final Report: "Impulse Testing of Rod-to-Rod-to-Plane Protective Gaps for VLF Antenna Systems."
12.	Appendix L:	Haiku Span Inspection Trip Report

SECTION 16D. FAILSAFE TYPE GUY STRAIN INSULATORS

16D.1 Scope. - This section includes failsafe type guy strain insulators.

16D.2 General. - These insulators shall be incorporated in the structural guys of the 1200-foot tower, in the halyard lines of the antenna panels and antenna panel catenaries as shown.

16D.2.1 Qualifications. - The electrical and structural requirements of the insulators specified herein are unusually severe. Each bidder shall be prepared to submit written data supporting the experience and capabilities of the manufacturer or manufacturers supplying all component parts of the insulators.

16D.2.1.1 Experience and capabilities. - The qualification data shall summarize the prior experience of the insulator manufacturer in the design, fabrication and testing of high strength, high voltage ceramic insulators. The summary shall include a description of the basic insulator types employed, the electrical and structural characteristics of the insulators, identification of projects on which the insulators were employed and other pertinent data. Particular emphasis should be placed on insulators capable of withstanding voltages ranging between 50 and 500 kv while wet, and tensile loads extending from 50 to 400 kips. The Bidder shall also summarize the test facilities to be employed in qualification testing of the insulators and his experience and capabilities in performing such tests.

16D.3 Applicable documents. - Except as specified hereinbefore in Division 1, General Requirements, the following specifications and standards of the issues listed and referred to in this section, including the addenda, amendments and errata listed, form a part of this specification to the extent required by the references thereto.

MILITARY

MIL-I-10B(1)	Insulating materials, eleczrical, ceramic, Class L.
MIL-I-23264(2) (Int. 4)	Insulators ceramic, electrical and electronic.

NON-GOVERNMENT

United States of America Standards Institute, 10 East 40th St., New York, N. Y. 10016.

C29.1 - 1961	Electrical power insulators.

American Society for Testing and Materials, 1916 Race St., Philadelphia, Pa. 19130.

A 123 - 68a	Zinc (hot-galvanized) coatings on products fabricated from rolled, pressed, and forged steel shapes, plates, bars and strip.
A 153 - 67	Zinc coating (hot-dip) on iron and steel hardware.
A 441 - 68a	High-strength low alloy structural manganese vanadium steel.

National Electrical Manufacturers Association, 155 East 44th St., New York, N. Y. 10017.

NEMA Publication No. 107 (Joint Coordination Committee on Radio Reception EEI, NEMA, and RETA).

16D.4 Performance requirements. - The failsafe type guy strain insulators shall meet the performance requirements specified herein.

16D.4.1 General description. - The insulators shall be made up of one or more insulator units which can be connected together in series to obtain the voltage insulating level required. Each insulator unit shall consist of two interlocking steel straddle frames positioned opposite each other with a ceramic body between, and so arranged that the planes of these straddles are along the insulator axis and oriented 90 degrees apart. The straddle frames shall be articulated in such a manner that no eccentric loading of any part of the insulator is permitted. When the units are connected together into a string, two axes of articulation at each porcelain unit 90 degrees apart shall be provided. Articulated joints shall be made with pins or bolts in double shear in such a manner that no eccentric loading of any part is permitted. Connections between units and between a unit and a guy fitting shall be by means of pins or bolts in double shear. Pins or bolts shall not be used in direct tension. The method of retaining the ceramic body within the straddle frames shall result in the frames and ceramic being in intimate contact and in compression to preclude voids and local hot spots in the insulator, to prevent rf noise and effectively transmit the required mechanical loads. The insulators shall be suitable for use at radio frequencies in the range of 15 to 30 kc and shall be tested with applied voltages as shown in "Table 1" of paragraph "Insulator characteristics". Grading rings shall be provided when required to obtain adequate grading of the individual units in a group.

16D.4.2 Insulator characteristics. - The insulators shall possess the physical and electrical characteristics contained in "Table I".

TABLE I - INSULATOR CHARACTERISTICS

Type Ident.	Safe Working Load (Kips)	Ultimate Strength (Kips)*	Approx. Length (in.)	Max. Weight Incl. Grading Rings (Pounds)	Max. Exp. Wind Area Incl. Grading Rings (S. F.)	Nominal Operating Voltage at Insulator Position (KV rms)	Min. Wet Flashover (KV rms)	Insulator Min. Wet or dry Corona-free Voltage (KV rms)
P-2	40	92	692	6000	75.0	250	500	313
P-4	110	254	648	7800	85.0	250	500	313
P-4a	110	254	60	500	4.0	---	---	---
P-5	150	345	648	9700	90.0	250	500	313
P-5b	165	380	72	800	5.0	250	500	313
P-5c	165	380	108	1200	7.0	250	500	313
P-5d	165	380	132	1700	17.0	250	500	313
P-7	220	507	804	13500	100.0	250	500	313
P-7b	220	507	84	1200	7.0	43	86	54
P-7c	220	507	120	1700	9.0	55	110	69
P-9b	330	761	96	2500	11.0	43	86	54
P-9c	330	761	132	3500	15.0	55	110	69

The length shown shall be measured between center lines of the end holes of the insulator or string to which the guy fitting is attached. The weight shown shall be the total weight (including end units) of the insulator as it is attached to guy sockets. The minimum wet flashover voltages apply to the complete insulator assemblies including grading rings and connecting hardware. The voltages specified relate to the following standard weather conditions: Temperature: 77 degrees F. Barometric Pressure: 29.92 inches of mercury. Vapor pressure: 0.6085 inches of mercury. Test voltage: KV rms, 60 cycle.

*Except that ultimate strength of all pin joints in straddle frames, including net sections through pin holes of frames, links and end pieces, shall be not less than 1.30 times the values listed.

16D.4.3 Environmental conditions. - These insulators shall perform satisfactorily under the following environmental conditions:

(a) Ambient temperature range 0 degrees F. to 100 degrees F.

(b) Rain from light mist to heavy rainfall.

(c) Winds from 0 to 90 MPH.

(d) Wind blown dirt and sand.

(e) Salt spray.

(f) Relative humidity of 100 percent with condensation.

(g) Ice and snow.

16D.4.4 The straddle frames, connecting links and other structural members shall be made from steel conforming to ASTM A 441 or equivalent with a minimum yield of 50,000 psi, or from other steels conforming to an ASTM specification. Bolts, or pins shall be made from steel conforming to an ASTM specification or approved equal. All ferrous parts of the insulator string, including fittings, attachment plates, and hardware shall be hot dip galvanized in accordance with ASTM A 123 and A 153, except that threading shall be done before galvanizing. The finished galvanized surface shall be smooth and free from wrinkles, sharp points, or other surface irregularities which might cause localized high electrical stresses resulting in corona.

16D.4.5 Rounding of edges. - The corners of all plates, fittings, and hardware shall be suitably rounded to avoid localized high electrical stresses which could result in corona.

16D.4.6 All ceramic parts of the insulators shall consist of materials of Class L, Grade 222 or better as defined in MIL-I-10. The surfaces of the insulators exposed to the weather shall be glazed to minimize contamination. No bare spots in the glazing will be permitted. The ceramic body of the insulator shall be free from surface blisters and shall have no sharp points or irregularities in the surface.

16D.5 Grading ring assemblies. -

16D.5.1 General. - There shall be grading ring assemblies at each end of certain insulator assemblies to improve voltage distribution across each insulator unit. The design of the grading rings shall be such that the overall voltage characteristics are met

and the operation of the assembly is corona-free and shall be such that the possibility of damage from self-induced vibrations is minimized. Design of grading rings is the responsibility of the Contractor, including detailed sizing and design to satisfy all structural and electronic requirements.

16D.5.2 Vibration suppression. - Consideration shall be given in design to the following in order to minimize the possibility of self-induced vibrations with consequent damage to the grading ring assemblies:

(a) Limitation of the slenderness ratio of tubular members.

(b) Use of spiral windings (spoilers) on tubular members.

(c) Details at joints to prevent fatigue failure.

(d) Use of high strength bolts tightened to specified values.

(e) Elimination of eccentricities.

16D.5.3 Special requirements. - All hardware in the grading ring assemblies shall have smooth surfaces and rounded exterior edges. All projecting heads, nuts, and threads of bolts and similar protuberances shall be treated to insure corona-free operation at the specified voltages.

16D.5.4 Materials for grading ring assemblies may be either aluminum or galvanized steel, as approved.

16D.6 Tests required. - Detailed test procedures for both mechanical and electrical tests, including the proposed method of establishing the environmental conditions specified herein shall be submitted for approval prior to the conducting of the tests. Test procedures shall follow the applicable portions of USAS Standard C29.1. Test procedure approval is required prior to conducting tests. All tests shall be by and at the expense of the Contractor.

16D.6.1 Heat rise test. - The following test shall be performed on one completely assembled insulator individual unit of each basic porcelain type. A voltage equal to the manufacturer's rated voltage of the insulator unit at 60 cycles (rms) shall be applied across the insulator and held for 30 minutes. The temperature rise in the ceramic body shall be determined and related to 15 kc.

The corrected temperature rise shall not exceed 30 degrees C. Testing of these units shall be made at 15 kc or at other frequencies, relating the heating effect at the test frequency to 15 kc.

16D.6.2 Proof test. - Each assembled insulator unit shall be tested at full working load for at least one minute. Tests may be made in strings, as approved. Any evidence of permanent deformation or of cement or ceramic cracking shall be cause for rejection.

16D.6.3 Mechanical test. - One complete unit of each of a manufacturer's type or size to be used shall be subjected to an ultimate strength test as follows:

(a) The unit shall be incrementally loaded to 50 percent of its safe working load. The load shall then be decreased to zero.

(b) The unit shall be incrementally loaded to 1.50 times its safe working load and held at this load for three minutes. The load shall then be decreased to zero. During the incremental loading and unloading sufficient data shall be recorded to enable a full load-deformation diagram of the unit to be made. At the end of this part of the test all pins and bolts shall be removed, inspected and photographed. Any evidence of permanent deformation or failure shall be identified and described.

(c) The unit shall be reassembled and tested to failure. Sufficient data shall be recorded to enable a full load-deformation diagram of the unit to be made. Load-deformation diagrams shall be made for all mechanical tests.

(d) Criteria for satisfactorily passing the test are as follows: No element of the assembly shall fail, the ceramic body shall not crack or spall, and no part shall deform sufficiently to impair the function of the assembly at 2.3 times the safe working load.

16D.6.4 Tests of welds. - All welds on the insulator frames shall be magnaflux tested. Refer to Section "Structural steel and miscellaneous fittings" for welding requirements and test requirements, except that all testing shall be performed by the Contractor at his expense.

16D.6.5 Electrical Testing of Insulators. -

16D.6.5.1 General. - The insulators shall be tested to establish their electrical performance in accordance with the provisions of this section and applicable portions of USAS Standard C29.1. At least 60 days prior to commencement of these tests the Contractor shall submit detailed procedures of his proposed test program

to the Officer in Charge of Construction for approval. The electrical tests of the insulators shall be conducted at 60 cycles and as far as practical shall be made in accordance with current USAS Standard C29.1. Each insulator type group, designated in paragraph, "Insulator characteristics" as P-2, P-4, P-5, P-7, and P-9, shall be subjected to electrical testing as defined herein. In the event that identical insulators meet the requirements for and are used to fulfill the needs of two or more insulator type groups as defined herein, the tests need be made only once for such type groups provided the test is made under the more severe requirements. The insulators within one type group may consist of one or more insulator units connected in series. In conducting the electrical tests for any one type group, the test shall be conducted first with the greatest number of units required in series. After removing one or more insulator units from the string the tests shall be repeated, and so on until tests have been completed on each insulator type identified in the first column of "Table I" in paragraph "Insulator characteristics". Tests shall be conducted on complete assemblies including insulator units, links, end units, hardware, and grading rings if required. RIV (radio influence voltage) tests, however, shall be conducted on each and every insulator unit as defined in paragraph "Radio influence voltage (RIV) test".

16D.6.5.2 Test setup and tests required. - The assembly shall be suspended in air in an outdoor environment with the lower end at least 25 feet above the ground. One end of the insulator assembly shall be connected to ground. The test voltage shall be applied to the other end of the assembly. Tests shall be conducted as specified herein.

16D.6.5.2.1 Corona-free dry and wet voltage tests. - The insulator assembly shall be tested to establish that it is corona-free (visual corona in the dark) under wet or dry conditions as set forth in "Table I". In conducting the wet corona test the insulator shall be allowed to drain after the application of water, until essentially all dripping has ceased, before the application of test voltage.

16D.6.5.2.2 Wet flashover voltage tests. - The insulator assembly shall be tested to establish that it will not flash over under wet conditions as set forth in "Table I".

16D.6.5.2.3 Voltage distribution test. - The voltage distribution across the insulator assembly shall be measured so that the voltage drop across each insulating unit is determined.

16D.6.5.2.4 Radio influence voltage (RIV) test. - Each individual insulator unit shall be subjected to a radio influence voltage test in accordance with the Joint Coordination Committee on

Radio Reception of EEI, NEMA, and RETA (NEMA Publication No. 107). Reading of noise level shall be taken starting at 90 percent of the normal rated voltage of the insulator unit and at regular intervals up to the corona formation voltage. Immediately after these tests are completed the unit shall be lowered and the insulators examined for evidence of local arcing or hot spots. Evidence of localized arcing or heating is cause for rejection.

16D.6.6 Witness of tests. - The Officer in Charge of Construction will witness the tests specified and shall have access to witness other tests and inspection procedures related to the procurement at any time. Inspection in whole or in part may be waived at the option of the Government.

16D.7 Drawings and data required of the Contractor. - The following shall be provided with the insulators:

(a) Assembly, installation and operating instructions.

(b) Drawing showing all part numbers, weights, dimensions, exposed wind areas and breaking strength capacities.

(c) Complete shop drawings of grading ring assemblies, including weight of the complete assembly.

(d) Evidence showing that fatigue resistance of all parts of the grading ring assemblies are adequate to prevent damage during the life of the installation.

(e) All test data, analyses, and extrapolations as related to each insulator assembly.

(f) Mill certificates, magnaflux reports, and all other pertinent information relating to materials and fabrication procedures of the insulator.

16D.8 Packing and shipping. - The spares specified to be delivered to the Officer in Charge of Construction shall be packed and crated for shipment (level A) in accordance with MIL-I-23264. The Contractor shall be responsible for packing and shipping insulators and appurtenances that he is to install. Detachable metal end units, frames, hardware fittings, and grading rings may be shipped separately from ceramic parts. All insulators shall be clearly identified and part marked to expedite identification and assembly in the field.

16D.9 Installation of the insulators. - The Contractor shall install the insulators in accordance with the manufacturer's

instructions. All such tests as may be required shall be made to demonstrate that no damage to the insulators was suffered in transportation or installation.

16D.10 Spares shall be delivered to the Officer in Charge of Construction at the jobsite, in the quantities specified herein. Terms used are as indicated on the drawings. End units shall be of the type required to accomodate the largest pin used with a particular "P"-number.

NUMBERS OF SPARES REQUIRED

Type Ident.	Ceramic Bodies (Units)	Straddle Frames (Pairs)	Connecting Plates (Pairs) & Pins (Fours)	End Units
P 2	6	3	3	3
P 4	6	3	3	2
P 5	12	6	6	3
P 7	10	5	5	5
P 9	8	4	4	4
Totals	42	21	21	17

16D.11 Basis of acceptance. - Acceptance of the insulators shall be based on compliance with all parts of the specifications, the tests outlined above and delivery to the Officer in Charge of Construction of all of the data required.

16D.12 Final acceptance shall be at the jobsite, regardless of previous inspections and/or acceptances in-plant or elsewhere.

--END SECTION 16D--

SECTION 16E. BASE INSULATOR

16E.1 Scope. - This section includes a tower base insulator under the 1200-foot tower.

16E.2 Applicable documents. - Except as specified hereinbefore in Division 1, General Requirements, the following specifications and standards of the issues listed and referred to in this section, including the addenda, amendments and errata listed, form a part of this specification to the extent required by the references thereto.

MILITARY

MIL-I-10B (1)	Insulating materials, electrical, ceramic, Class L.
MIL-I-23264(2)(Int.4)	Insulators, ceramic, electrical and electronic.

NON-GOVERNMENT

United States of America Standards Institute, 10 East 40th Street, New York, N. Y. 10016.

→ C29.1-1961 Electrical power insulators.

National Electrical Manufacturers Association, 155 East 44th Street, New York, N.Y. 10017.

NEMA Publication No. 107 (Joint coordination committee on radio reception EEI, NEMA, and RETA).

16E.3 General requirements. - The 1200-foot tower will be insulated from ground by a base insulator which not only provides electrical insulation but also carries the full down thrust and shear loads imposed by the tower. The base insulator shall be equipped with rain shields, a lightning protection ball gap and grading rings for corona protection. The base insulator shall be compatible with the tower foundation base plate and the tower base rocker assembly.

16E.3.1 Qualifications of base insulator manufacturer. - Data shall be submitted showing proof of successful and continuous experience within the past 5 years in the design and manufacture of ceramic insulators capable of operating at radio frequency voltages between 250 kv and 500 kv and capable of carrying mechanical loads in the range of 2.5 million pounds in compression.

16E.3.2 Base insulator performance requirements. - The base insulator shall be of any one of the following types: multiple element oil filled ceramic cylinder; multiple element ceramic

cone, either hollow or solid; or multiple ceramic cylinder. The insulator shall have a corona-free safe-operating voltage rating of 250 kv, rms, under either wet or dry conditions within the range of 15 kc to 30 kc and shall have a minimum flashover rating, wet and dry, of 400 kv, rms. The insulator shall be capable of resisting a vertical compressive working load from the tower of 2.5 million pounds and a concurrent transverse shear of 25,000 pounds in any direction, both forces being applied at the top of the base insulator.

cf Para 16.E.3.3.1

freq. not specified

16E.3.2.1 Ceramic parts of the insulator shall comply with MIL-I-10 Grade L, 243 or better. The ceramic surfaces exposed to the weather shall have a chocolate brown glazed finish. No bare spots in the glazing will be permitted. The ceramic bodies of the insulator shall be free from surface blisters and shall have no sharp points on the surface.

16E.3.2.2 Structural metal parts shall comply with the requirements of Section "Structural steel towers and guy anchors".

16E.3.2.3 Rain shields shall be provided as a part of the base insulator. The outside edge of the rain shield shall be graded to prevent corona. Such grading ring shall have a minimum tube diameter of 4 inches.

16E.3.2.4 Lightning protection. - The base insulator shall be provided with an adjustable lightning protection gap which is sized and configured in such a manner that provides protection to the base insulator from a lightning stroke.

16E.3.2.5 Environmental conditions. - The base insulator shall perform satisfactorily under the following environmental conditions:

(a) Ambient temperature range 0 degrees F. to 100 degrees F.

(b) Rain from light mist to heavy rainfall.

(c) Winds from 0 to 90 MPH.

(d) Wind blown dirt and sand.

(e) Salt spray.

(f) Relative humidity of 100 percent with condensation.

16E.3.2.6 Base insulator heaters shall be provided to prevent the formation of high capacitance moisture film on oil filled ceramic cylinders during severe weather conditions. These heating elements shall be 230 volt ac and shall be thermostatically controlled.

16E.3.3 Testing of base insulators. - All tests shall be by and at the expense of the Contractor.

16E.3.3.1 Electrical tests. - The base insulators shall be tested as described herein to determine the electrical characteristics. The manufacturer shall provide test facilities to conduct the tests and shall submit reports describing all tests and results. The test plan shall be submitted for approval 60 days prior to testing. The Officer in Charge of Construction shall be allowed free access at all times to witness tests and to perform inspections.

16E.3.3.1.1 Sixty-cycle wet flashover test. - This test shall be made on one complete insulator assembly. The insulator assembly, with grading rings, rain shields, and lightning gap, shall be tested in a suitable high voltage test area. Voltages shall be applied to the upper end of the insulator with the lower end grounded and resting on an equivalent ground plane 10 feet square to simulate the insulator environment. The test shall conform to USAS Specification C29.1, Paragraphs 4.2.2., 4.2.4., 4.2.5., 4.2.6., and 4.2.7.

16E.3.3.1.2 Wet and dry corona free voltage. - The test set-up shall be the same as the 60-cycle flashover test and the test made to conform to USAS Specification C29.1, Paragraph 4.6.4. Separate tests shall be made for corona point under both wet and dry conditions. cf para 16E.3.2

means whole unit assembly (?)

16E.3.3.1.3 Radio influence voltage (RIV) tests. - The individual base insulator unit shall be tested at 250 kv (rms) at 60 cycles for radio noise in accordance with USAS Specification C29.1, Paragraph 4.5., or in accordance with the Joint Coordination Committee on Radio Reception of EEI, NEMA, and RETA (NEMA publication No. 107). Any unit that shows visual corona or more than 30 microvolts noise shall be corrected or rejected. Any unit that flashes over shall be corrected or rejected.

16E.3.3.1.4 Heat test. - A voltage equal to the rated voltage (rms) of the unit at 60 cycles shall be applied across the insulator and held for 30 minutes. The temperature in the ceramic body shall be determined and related to 15 kc. The corrected temperature rise shall not exceed 30 degrees C. Testing of this unit shall be made at 15 kc or at other frequencies, relating the heating effect to 15 kc.

RF

doesn't say what it is

16E.3.4 Mechanical tests. -

16E.3.4.1 Ceramic parts. - Each ceramic part to be used in the insulator shall be tested at two times the rated safe working load. After the load has been removed the part shall be tested for electrical soundness.

84710/67-16E-3

16E.3.5 Protection from damage. - Damage to any component of the insulator assembly which cannot be acceptably repaired shall be cause for rejection. Rough or careless handling and improper preparation for shipping will not be tolerated. Containers and handling procedures shall protect all components from damage at all times. The insulator assembly components shall not be exposed to possible damage from construction equipment. The Contractor shall provide new components to replace damaged components at his own expense and shall not be entitled to claims against the Government for extra payment or extensions of contract time arising therefrom. The special measures required to minimize the possibility of damage shall be submitted for approval. Such approval shall in no way relieve the Contractor of responsibility. The necessary surveillance shall be provided by the Contractor to insure that the approved measures are used. The Officer in Charge of Construction will inspect the components at the manufacturer's plant for damage. The Officer in Charge of Construction will make a special inspection of the assembly just prior to installation.

16E.3.6 Packing and shipping. - The Contractor shall be responsible for packing and shipping insulator and appurtenances. All components comprising the complete insulator assembly shall be marked, packed, and shipped in such a manner that final assembly can be readily made at the site by the erection crew, with due regard to the requirements of paragraph "Protection from dage".

16E.3.7 Drawings and data required of the Contractor. - Complete shop drawings, materials specifications, and all other pertinent data shall be submitted for approval prior to manufacture of any of the insulator components. This data shall include detailed field assembly instructions.

--END SECTION 16E--

M E M O R A N D U M

M-2100-191-72
28 August 1972

From: Code 2100

To: NAVELEX PME-119, CDR Richardson

Subj: Preliminary informal opinion re attainment of 275 kV WFO OMEGA guy insulators

Ref: (a) 11019/3 ser 521 PME-119 of 23 Aug 1972

1. Perusal of the 19 enclosures of reference (a) indicates to me that the attainment of the specified WFO has not been demonstrated. There are serious questions about the wetness of the insulators at the time of the tests, and there appears to be no way from the work performed to data to resolve the question about the differences in claimed voltage distribution. The method of observing corona is open to some doubt in view of the distances to the object.

2. Tests should be run again with standard water, delivered at a known rate and coverage. Questions about voltage distribution should be resolved unambiguously, and the ability of the entire assembly to meet required WFO should not be decided on the basis of test of a single component and projection to the entire unit based on voltage division ratios. Use of model data is not applicable unless it can be demonstrated that the model is accurate as to environmental effects on distribution of voltage.

3. There are ambiguous areas in the revised specification and use of 60 Hz tests is indicated, especially drip-dry tests which are irrelevant in showing corona-free operation under real-life conditions at vlf. Specifically,

16DX.6.1:	"adequate" grading should be defined
16DX.8.2:	ambient temperature against which temperature rise is to take place is undefined
16DX.8.5.2.1:	corona drip dry test is called out: this should be spray test
16DX.8.5.2.3:	What is "undesired distribution?"

4. I shall be in the PME-119 office Friday, 1 September 1972, or in any case in contact with some of the staff earlier in connection with the Ad Hoc committee meeting and I shall review the material in more detail in the meantime.

Andrew N. Smith

ANDREW N. SMITH

Copy to:
NELC Code 2170
2100

APPENDIX B

Enclosure (1) to
NELC ltr ser 2100-473

M E M O R A N D U M

M-2100-190-72

From: Code 2100 25 September 1972

To: Code 2170

Subj: Tests of La Moure, ND failsafe insulator sets Q4d and Q5d

Ref: (a) 11019/3 ser 521 PME-119 of 23 Aug 1972
(b) Trip report of 28 Aug 72-1 Sep 72 by A. N. Smith/NELC
(c) Fonecon between LT R. Gallen/NAVELEX PME-119 and A. N. Smith, C. J. Casselman/NELC of 13 Sep 1972
(d) NELC memo to PME-119 from A. N. Smith of 28 Aug 1972

1. Reference (a) asked NELC OMEGA project personnel to review 19 enclosures thereto in an effort to form an informal opinion concerning whether the subject insulators had been properly qualified per the procurement specification for performance in the La Moure transmitting station tower. Paragraphs 1, 2, and 3 were complied with by the writer on 28 August 1972 by reference (d). During the visit to NAVELEX PME-117 and PME-119 documented in reference (b) the subject was discussed and the opinion rendered in reference (d) was reiterated; namely, that in the writer's opinion the subject insulators had not been properly qualified for use in the tower structure by the tests reported and discussed in the correspondence represented by the 19 enclosures to reference (a).

2. Notwithstanding the submission of reference (d) and the conversation reported in reference (b), a further request for opinion was made in reference (c). At this time further examination of the material of reference (a) indicated that several essential correspondence items appeared not to be in the possession of the writer and PME-119 responded that they would supply same, specifically Woerfel Corp. submission of 4 May 1972, #417, concerning the tests of insulators Q5d. This was actually sent several days later by Holmes and Narver. Telephone conversations since 22 Sep 1972 reported to the writer by C. J. Casselman but not participated in directly by the writer, indicate that it is now the desire of PME-119 to make the opinion of reference (d) a part of official record. This appears to be motivated by the pressing of claims for extra expense by Woerfel against the Navy for additional qualification testing of the subject insulators that may have been beyond scope of work.

3. Accordingly, the writer hereby submits paragraphs 1, 2, and 3 of reference (d) as his official opinion concerning the qualification of the insulator sets Q4d and Q5d by the tests as described in the correspondence available to him. Further, it is to be remarked that in none of the correspondence available up to this date makes clear whether the <u>entire</u> assembly of two sets of two yokes of insulators (comprising in the case of Q4d 8 posts, and for Q5d, 10 posts) was tested for WFO or whether each set of two yokes in the cascade was tested individually and the WFO for the entire assembly inferred from the voltage distribution between them, which is a matter under dispute. Moreover, in references to water delivery rate, the least vague statements in submissions 416 and 417 give "7-1/2 gallons per minute <u>estimated</u>" (my emphasis) with no claim as to actual measurement, or as to whether this amount and rate was delivered by the pump into the hose, or whether this was delivered at the nozzle, and if the latter, over what projected area this was sprayed so as to enable a calculation to be made of delivery in tenths of inches depth per the AIEE standard.

Enclosure (2) to
NELC ltr ser 2100-473

In consequence the condition of the insulator surfaces during the execution of the tests is open to dispute relative to whether conditions required for a standard spray test were indeed satisfied, and the correspondence does not answer this question.

4. It is thus this writer's opinion, based on information available to him, that the WFO qualification tests for these insulators as described are inconclusive, and that unambiguous witnessed tests remain to be carried out. It should be noted that not all of the material referenced in the correspondence included in the 19 enclosures of reference (a) is available, although some of the items are recognized as contained therein. A crucial part of the chain appears to be enclosure (7), to which no satisfactory reply in the form of firm data or information other than opinions and allegations has ever been made by Woerful. Enclosure (14) is as good a statement, concerning the WFO level to which the insulator sets have been demonstrated, as any, and this writer agrees with its conclusions. Enclosure (16) involves reasoning and references that are totally obscure to this writer, and the conclusions drawn do not appear to follow.

Andrew N. Smith

ANDREW N. SMITH

REVIEW AND COMMENT ON INSULATOR RATINGS AND TESTS

by

Andrew N. Smith

26 January 1972

Radio Technology Division, Code 2100
NAVAL ELECTRONICS LABORATORY CENTER
San Diego, California 92152

APPENDIX B-2

Enclosure (1) to
NELC ltr ser 2100-39

During a visit to the PME-119 office on 19 January 1972, the author was asked to review pertinent documentation concerning the testing and rating of certain insulator units incorporated in the OMEGA Navigation Station antenna at La Moure, North Dakota. Motivation for this review was Navy/contractor controversy over the occurrence of a crack in a base insulator porcelain at Annapolis during initial high voltage tests and concern over the consequence of possible similar occurrence at La Moure in view of the erection of the tower and the incorporation in the guys of insulators that have not passed all high voltage tests to required specification despite Navy nonacceptance of these units. A statement as to the advisability and safety of conducting tests and definition of a safe upper limit was asked for.

Although the sub-contractor consultants (Westinghouse) to the Architect-Engineer for design (Holmes and Narver) have already taken a position not recommending approval of the insulator sets in question unless adequate standard tests under relevant conditions are carried out and successfully passed, PME-119 desired an independent evaluation of the same information carried out by NELC. In the time available between this request and the expected start of high voltage station tests (about 1 February 1972), a complete reevaluation has not been possible but the documents containing the main points have been examined. These and pertinent telephone conversations covering topics contained in reports submitted by Westinghouse are listed here as references (1) through (12).

The units whose ratings may be exceeded in the application to the La Moure tower are fail-safe guy strain insulator sets Q4d and Q5d and the tubular strain insulator units when used in the tripod pull-off structure. Sets whose ratings appear to be questionable are the tubular strain insulator units when actually used in the topload members and the base insulator. This report will consider conditions for each of the four insulators in turn, and attempt to recommend a safe procedure for initial testing under high voltage for freedom from corona under dry conditions. However, this procedure will have no bearing on subsequent recommendation for acceptance or rejection of the insulator sets for all weather conditions if it is performed by the Navy for dry weather.

According to Westinghouse personnel (8, 9, 10), the ratings for the insulators in the various positions were arrived at for the specification (1) through a fairly detailed electrolytic tank model study of the voltage distribution in the region around the tower and specifically of the distribution across the gaps in the guys caused by the presence of the insulators. Following a practice similar to but somewhat less conservative than the electrical power industry, a factor of two was applied to the experimentally determined expected maximum operating voltages for arriving at required wet flashover voltage. The more conservative and expensive factor of 2.75 used in power distribution systems is generally not permissible in vlf radio structures because of a more severe limitation on weight and cost versus performance mainly related to the greatly increased distances involved in the free spans for the conductors and consequent loadings. The multiplier for the specification of WFO versus operating voltage allows for surges due to electrical storms and for degradation of insulation quality due to contamination and aging. The figure for dry flashover voltage (DFO) is usually also mentioned as part of the description of an insulator but this rating is not usually considered relevant to the worst condition of operation.

For economic reasons based both on efficiency of operation and on avoiding premature destruction of materials brought about by operating in an ionized environment, it is also required that the insulator sets operate corona-free under the worst case condition. The relation of corona-free voltage to the flashover level is not simple, being dependent on the selection, arrangement, and finish of field-grading devices at the ends of the insulating material columns; but experience indicates that attainment of an extinction level of voltage for corona in wet conditions of 25% greater than the maximum operating voltage (or conversely 63% of the wet flashover voltage when this is defined as twice the maximum operating voltage) by proper design and installation is a reasonable expectation and is usually safe in operation, especially when also properly designed arc-gap protective devices are installed in the system and suitably adjusted. The corona onset level is higher than the extinction level so that an assembly in normal operation that is momentarily driven into corona is self-extinguishing when the surge dies away. The above choice of extinction level allows a suitable margin between corona onset (or withstand) level and WFO (momentary surge) so that corona onset does not necessarily also lead to flashover. Beyond these considerations is effect of accumulated surface contamination since the ratings described above are considered to be met by insulators in new and clean condition when tested according to the NEMA standards. Allowance for subsequent degradation is contained in the ratio of WFO to safe operating voltage.

From the above one can see that the ratings for the guy insulators based on the experimentally derived operating voltages are consistent with present day practice. The ratings required for the base insulator are not as conservative but are considered acceptable based on accessibility for cleaning and changing out if necessary. On the other hand, it is reasonable to make the rating for the topload span insulators somewhat more conservative because of the relative difficulty in access and because for reasons of economics they were of the strain type and not structurally fail-safe. The figures are all summarized in table 1.

Review of the correspondence concerning the Q4d and Q5d insulator sets with reference to the requirements described above (2 through 8) reveals several sources of possible shortcoming. First of all, this author can only concur with Westinghouse that if the wet tests were conducted as described they do not fulfill the NEMA requirements as to rate of wetting of the porcelains and therefore are inconclusive at best. Second, the attempts to demonstrate the voltage division between the two units of the sets closest to the towers give results for geometrical conditions completely different from those of the actual installation and are therefore irrelevant. The division was measured for a condition in which only the Q4d or Q5d set was in the guy and placed against a tower that had no topload. In addition, the sequential means of determining the voltage division across the string by measuring the arc gap voltage on one member of the pair with the other shorted across in no way duplicates the conditions of use. The results here seem to be that the most favorable split could be 60/40 versus a less favorable split of 70/30 between the two units for a total of 131 kV. The third aspect is that this total at this location pertains to model results in the tank for which the dimensions were chosen to represent a continuous string of several compression cone type units instead of the combination of two units connected by a long conductor in the presence of two more single units in both cases. For the condition actually in use, the voltage across the combination at units Q4d or Q5d could

well be in excess of the 131 kV used as a basis for specifying the ratings. Table 1 indicates that in the most favorable case of the 60/40 split the topmost unit of the pair could well be working at 80 kV. Quite apart from any of the other considerations in view of the fourth aspect, namely, that the fifth (center) porcelain in the pantapost combination is rated for a normal working voltage of 46 kV and a wet flashover rating of 125 kV it is apparent that this unit is being worked greatly in excess of the normal manner for its stated rating, specifically, 70% in excess as a minimum. If the voltage split is less favorable or if the total across the combination is more than the 131 kV, either condition necessarily having to be regarded as probabilities then the center element of the pentapost unit there is even more overstressed. Note that this remark would not apply if it could be demonstrated at full scale that, in a geometry comparable to that actually in use, the insulator set did indeed withstand the full rated wet flashover voltage (not just the expected operating voltage). One could concede that the ratio 125/46 = 2.75, per the power company practice in which case it might be fair to say that the revised permissible working load would be 62.5 kV in the vlf application. Even if this is done, 80 kV represents a 30% overload compared to a probable (theoretical) wet corona limit of 75 kV so that while no trouble may be experienced for tests in dry conditions, there may well be a problem with corona during wet, especially after a period of aging and contamination. Note that this condition applies without any reference to what could be the case in event of failure of a unit lower on the string.

For the main topload strain insulators, a calculation of inductive voltage rise for 10.2 kHz indicates that at 10 kW radiated the voltage on the cables may be in the neighborhood of 230 kV for a mean topload voltage of 220. If all this appears on the main units then the implied WFO rating on the usual basis would be 460kV. The results quoted in Table 1 from reference (9) show an expected division between this and the others of 171/31/19 for 220. Therefore it could be argued that it would be fair to require only 360 kV WFO or that certification to 400 kV would be adequate. However, this would ignore completely the effects of catastrophic failure of one of the outer units. To assure nonfailure of the tabular unit in this situation, it does not seem unreasonable to insist on the full 500 kV WFO rating for these units although in normal operation it is unlikely that corona will be observed either wet or dry. In this connection, however, a question has been raised by Westinghouse concerning the placement of the corona ring and the supports which physically appear to resemble a grading ring, the location of which does not protect shackles and other hardware items outboard of the caps of the insulators. Finally, no reference available to this author to date indicates that this insulator has ever been subject to high voltage test in the configuration to be used in the main spans. It has been tested in the tripod arrangement to be used for the pull-off structure but there are questions outstanding about the validity of these tests which lead to a claimed rating of 410 kV for WFO versus the specified 500. It is unlikely that tests in dry conditions to 220 kV will yield any indication of trouble, however; but these tests would be inconclusive relative to the meeting of the specification.

Both the tripod pull-off and the base insulator sets are stated to have passed WFO tests to 400 kV but Westinghouse has questioned the conditions of the wetting of the porcelains and the use of grading protection for hardware items in configurations other than that to be used in the actual installation (10). A figure of 152 kVrms has been mentioned as observed corona extinction

voltage for some of the tests. Therefore, while it would appear that operation to 220 kV under dry conditions may be safe, this cannot be a priori assumed. Moreover, successful operation in such a test would yield no conclusion about operation to the limits specified for wet conditions.

In November 1971, base reactance measurements were carried out on the antenna preparatory to locating the tapping points on the helix. This was done according to a test plan written at NELC (13). A curve of reactance (12) versus frequency is available that indicates that the actual values in the normal operating frequency range of the antenna are within 1.5% of those predicted by Westinghouse (11). From this curve the base reactance at 9.8 kHz, the frequency chosen for the high voltage tests, is 578 ohms. Therefore a current of 365 amperes is permissible to stay within a voltage of 211 kV at the base or 220 kV mean topload voltage. Assuming that the effective height of the antenna is as predicted, the radiation resistance projects from 0.071 ohms at 10.2 to 0.066 ohms at 9.8. It follows that radiated power at this frequency will be 8.8 kW. Preliminary base resistance measurement with unfrozen soil during these tests were made so as to have a basis for comparison with values to be determined for final measurements which will be made during a season when the soil is frozen. If the helix coil Q and tuning system losses are comparable to what are expected at Haiku for which an expected tuning system Q of 2900 resulted, then the antenna system losses for unfrozen ground turn out to be 0.70 ohm. The frozen condition may lead to an additional 0.05 ohm ground loss or a total of 0.75 ohms. The antenna system efficiency may therefore be expected to be about 8.8% during the high voltage tests under frozen soil conditions at 9.8 kHz and thus the required power delivered to the system at the matching transformer terminals is 100 kW. Since the specified minimum power capability required of the transmitter at this point is 135 kW, the high voltage tests to be performed under the voltage limit of 220 kV on the topload will not constitute a full power test of the transmitter even with the soil at the site frozen. Conversely, a full power test of the transmitter under present conditions will exceed the voltage on the system that the insulator supplier has indicated is acceptable since this would yield 11.8 kW radiated and a base current of 420 amperes or 243 kV base voltage (255 mean topload voltage). Correspondingly, a test to 10 kW radiated would only require 114 kW delivered and thus would not constitute a full power test of the transmitter. For this situation the base voltage would be 226 kV and the mean topload voltage 236 kV, still in excess of the 220 permissible. At 10.2 kHz the situation is no better since the currents, projected efficiency, and permissible voltages yield 10 kW radiated with about 105 kW delivered.

A corollary of the above discussion is that such power tests as can be run under the voltage limitation of 211 kV on the base will in no way constitute full-power heat runs for the matching and tuning components even if this were to be done in the summertime under high temperature conditions. At present, with an unheated helix house, this would be true even if full-power could be absorbed from the transmitter and no question existed about the insulators. Full-power test of the transmitter by itself are possible only by using the dummy load.

The conclusions therefore are that with the supplier's limitation on permissible insulator voltage (1) at 9.8 kHz no more than 365 amperes base current is allowable; (2) initial detail examination of the system for corona should start at a level no higher than half this value, 185 amperes with particular attention being directed at the pull-off and Q4d and Q5d insulator sets; (3)

tests must be done during dry conditions and therefore no conclusion can be reached about the acceptability of the insulators at these locations or at the base, feed bus, or main topload strain sets for wet condition; (4) no meaningful full power heat run or full transmitter load tests are possible with the antenna system in the circuit.

TABLE 1

INSULATOR CHARACTERISTICS AT LOCATIONS OF SUSPECTED WEAKNESS

Identification	Experimentally Predicted Operating Voltage* kV	Nominal Operating Voltage kV	Specified WFO kV	Specified wet corona withstand kV	Most probable actual rating kV
Q4a lower	48	50	100	62.5	130 WFO
Q4a upper	43	50	100	62.5	130 WFO
Q4d	131	137.5	275	172	46 operating† 125 WFO† 140 wet corona†† (179 later test)
Q5a lower	38	50	100	62.5	128 WFO
Q5a upper	51	50	100	62.5	128 WFO
Q5d	131	137.5	275	172	46 operating† 125 WFO† 163 wet corona††(177 earlier test)
Main Span Tubular	225-230**	250	500	275	?
Base	21	220	400	---	400 DFO (Westinghouse) 400 WFO (Woerfel)
Pull-off Tripod	211	220	400	---	152 wet corona extinction 168 dry corona extinction 400 WFO

*for 10.4 kW radiated @ 10.2 kHz, h_e=197 meters, C_o=0.0271μF, V_t=220kV
**171 for tubular strain unit, with 31 and 18 1/2 on upper and lower Q4a in topload halyard, assuming 220 kV on entire string

†Figures for central member in penta-post set
††Claimed test results

References:

1. Insulator Specifications, pages 21-69-0095-16DX-4, 16E-2, 16F-2, 16G-1.

2. Nash, R. G., "Fail-safe Insulator Test Evaluation," of 2 Jun 1971.

3. N62477-69-C-0095 ser 880 DRW/drw of 23 Aug 1971.

4. Westinghouse sketch of Fail-Safe Guy Strain Insulator Tests of 24, 25 Sep 1971, Dallas, Texas

5. Castro, I. C., General Electric ltr to C. M. Smith of 27 Sep 1971; Subj: High Voltage Test of Insulators for Continental Electronics.

6. Test Report HVL-71-274, RIV Tests on Guy Wire Insulator Types Q4d and Q5d for Continental Electronics of 29 Sep 1971.

7. N63477-69-C-0095 ser 947 RMG/drw of 7 Oct 1971.

8. Westinghouse Electric ltr of 13 Jan 1972 to Holmes & Narver; Subj: Technical Rebuttal to Woerfel correspondence of 16 Dec 1971.

9. Fonecon, A. N. Smith/ B. G. Hagaman of 19 Jan 1971.

10. Fonecon, A. N. Smith/ B. G. Hagaman and W. D. Detwilier of 25 Jan 1971.

11. OMEGA System Characteristics, revision 3-2 by Westinghouse of 2 Apr 1971.

12. Table of Base impedance characteristics, unpublished results from preliminary tests of La Moure, North Dakota antenna system.

13. Antenna Base Measurements Part A of Antenna System Test Plan, Enclosure (1) to NELC ltr ser 2100-304; TED:bsb of 15 Oct 1971.

TEST PLAN FOR L^3 BASE

VOLTAGE AND SPURIOUS COUPLED-IN VOLTAGE MEASUREMENTS

18 MAY 1972

PURPOSE OF TESTS:

1. Measure ratio of bushing voltage to tower base voltage at VLF.

2. Test for voltage division across base insulator, calibrate system; try grading ring to equalize voltage division.

3. Test for presence of LF induced voltages that may be a harmonic of VLF operating voltage to which system is tuned, both ambient and induced; also look for transmitter harmoni s.

4. Test for presence of atmospheric or other transients, both at ambient levels and as induced in the VLF antenna system.

5. Apply results of 1 through 4 above to determine existence or not of excessive voltage leading to arc-over of the rod gap at tower base and to devise a means of preventing same.

PROCEDURE:

1. Voltage rise and calibration measurement. Make connection as indicated in schematic in Figures 1 and 2. Voltmeters No. 1 and 2 are Jennings voltmeters. At both places a tuned voltmeter can also be paralled through a divider. Make connection with transmitter off and antenna grounded. Unground antenna and raise CW excitation to a low level not to exceed several thousand volts base. Record readings of voltmeter 1 and 2, starting with 2 connected to the tower base. Make initial setup at West tower. Reduce excitation to zero, reconnect VM #2 to intermediate and low level rain shield (points b and c) in turn, repeating the readings of voltmeter for each condition. Repeat entire sequence for all VLF frequencies that are available. Excitation can be either by FRT-64 or by auxiliary source such as MacIntosh 240 connected at the plate tank terminals in the PA. This sequence is done at West tower. Figure 3 gives connection details.

2. a. Set up for similar measurement at East tower. In addition, set up shielded hut, position sphere probe and place instrumentation inside hut making connection at point 3. With Jennings VM #2 on measuring point 2c, repeat all of step 1 making a determination of voltage at point #3 with all instrumentation connected, using HP 302. Record only Jennings VM #1 and #2 at points 1 and 2. After low level measurement is complete, repeat using FRT-64 at normal power level. During full power tests record base current; if calculation of bushing voltage indicates that it is permissible, use Jennings VM #1 to read base voltage directly. Figures 3 and 4 show complete test setup. Figure 5 shows conceptual view of shielding hut.

b. Repeat A using temporary grading ring to optimize division across units. (Figure 6).

APPENDIX C

Enclosure (1) to
trip report

3. a. Under full-power conditions, either CW or FSK with circuit as in Step 2, use HP 302 and 310 in turn to measure spectral distribution of tower base voltage throughout the VLF and LF bands. Information from steps 1 and 2 provides calibration figures. Pay particular attention to frequencies determined from LF field strength survey of Step 3c below. Also look for significant transmitter carrier harmonics. Look for coincidences of rod-gap strike-over and LF voltages on base.

b. Under key-up conditions with FRT-64 and helix and antenna system otherwise in full operating condition, make complete scan of VLF-LF spectrum as in 3a above. The capacity division may be altered if necessary by shunting the gap from the rain shield to the sphere probe with a fixed mica capacitor. Additional calibration capability is available by use of the HP 350 test set, at the connection point indicated in Figure 4. Record voltages observed, if any, for resonant peaks in the range. Pay particular attention to frequencies determined from the LF field survey.

c. LF ambient signals will be measured by NAVSEEACTPAC in accordance with NAVELEX msg P 151920Z May 1972. The frequencies of such signals will be those considered suspect in steps 3a and 3b above. P_r and distance to such stations from both towers will be requested from NAVCOMSTA Lualualei.

4. Although not shown in the diagram of Figure 4, it is assumed that there is available a URM 6 or Empire 105 or equivalent RIFI meter. This will be set up in the shielded hut with the antenna inside but available to be moved outside during actual down-time measurements. During measurements of broad-band transient phenomena by means of the 181A memoryscope with multichannel vertical amplifier and time base and delay generator, coincidences will be looked for between the transients displayed on the oscilloscope vs threshold level and atmospherics detected with the RIFI meter. The transmitter, helix, and antenna will be in key-up condition witn the antenna system ungrounded. Under operating conditions, either CW or FSK, the set-up is the same but the RIFI meter is not used and a high-pass filter is used in series with the input to the oscilloscope amplifier. The HP 350 set gives a calibration capability for either condition for amplitude level. A sequence of repeated trials will be used with increasing threshold levels to determine coincidences of atmospherics with rod-gap arc-overs. Polaroid photos will be taken of such transients.

5. Ratios of bushing voltage to tower base voltage will be calculated to determine that these are as expected from design criteria at the VLF carrier frequencies. Superposed LF signals that are induced from neighboring transmitters may be harmonically related to the VLF frequency such that a voltage loop apperas at the LF frequency at the field point, giving sufficient overvoltage to lead to a rod-gap strike-over. The same is true of the transient voltages. The necessary overvoltage is a function of atmospheric conditions. Hopefully, the time frame of the on-the-air portions of the tests (Steps 3 and 4) is sufficient to enable significant coincidences to be observed. The instrumentation is adequate to detect the presence of LF signals which may be the cause of triggering the carrier cut-off device used in the rod gap as an apparent modulator. The output of this device will be monitored by station personnel who will inform the test engineers in the test but when such a phenomenon occurs, they will look for the LF signal with the tuned voltmeters at the time their attention is called to it. Also in Step 3, using the additional equipment terminals (Figure), a true rms meter and an average reading meter (403A) can be employed to give indication to V_d to characterize the total base voltage waveform.

EQUIPMENT LIST

Electronic Items:

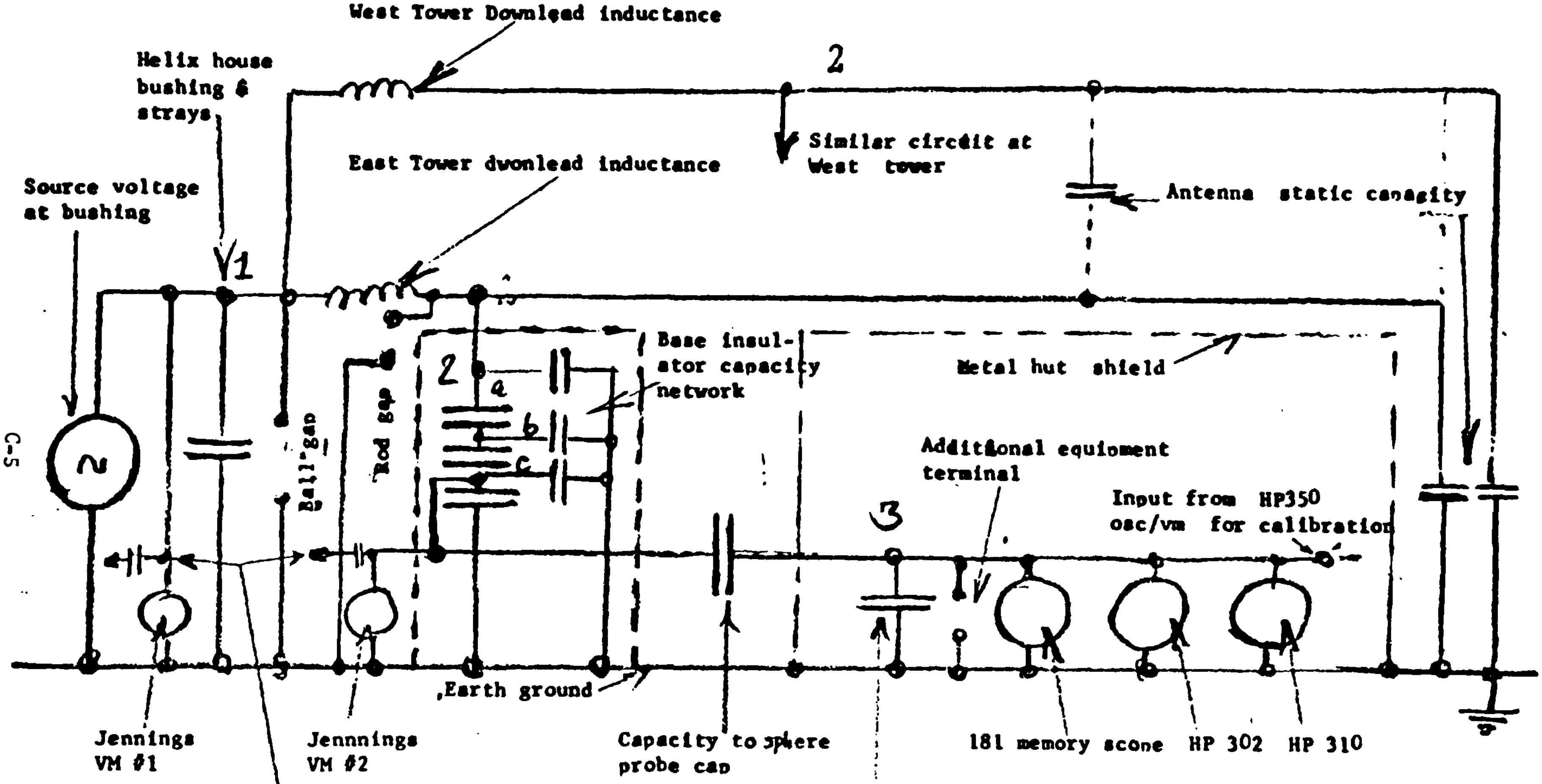
HP 181A   Memoryscope
HP 1804A 4-channel vertical amplifier
HP 1821A Time base and delay generator
HP 350A   Test set
HP 310A   Distortion analyzer
HP 302A   Wave analyzer
HP 403A   VM
HP 522A   Counter
HP 466A   AC amplifier
Polaroid scope camera and bezel
URM-6 or Empire 105 RIFI meter
Jennings J-1004 VM
Jennings J-1003 VM
Chicago isolation transformer 150VA
High pass filter 500 kHz rolloff
Triplette 630 M multimeter
Coax connector fittings and terminal fittings
Jennings capacity voltage divider

Tools and Hardware:

Battery for 302 A
Metal hut 5' x 6' or larger, not to exceed 8' x 8'
1/4" square hardware cloth mesh, 4' x 16'
8 x 2" x 4" x 8' studs
2 x 4' x 8' x 3/4" A&C exterior grade plywood sheathing
2" x 12" x 6' plank
2" x 6" x 6'
Multiple electric sockets
Multiple electric plugs
2 to 3 prong socket adapters
Trouble light
5# 10 d hot-dipped galv. nails
2" x 3/8" bolts, nuts, flat washers, preferably stainless, 2 doz.
3/4" x 5/16" bolts, nuts, flat washers, preferably stainless, 3 doz.
50' extension cord, 4 socket
18" x 24" x 1/4" al, stressplate
1-1/2" x 5' pipe
9" copper sphere and probe
2 x 24" x 1-1/2" angle bracket
tool box, assorted hand tools
box assorted nuts, bolts, capacitors
1/2" power drill, ser 13677
bitts
litz connector
soldering iron
Type 107 film, 78 exposures/ 6 packs

Figure 5 shows a conceptual exploded view of the test hut construction. As far as possible, it will be pre-assembled outside of the high field region of the VLF antenna and then carried into position on a cart. This will not require station down time. Down time will be required for making the connection to the base insulator rain shields and for initially adjusting the capacity divider gap. Because of the high voltages involved and the consequent size of conductors for gradient control, it may not be practicable to make direct determination of base voltage at the bushing under high power conditions with the Jennings voltmeter. If this is the case, the determination of voltage rise will be made at low level only.

Note: There is 60 Hz power available at the tower base for instrumentation supply: Filtering of VLF must be made by isolation transformer at mains connection



Capacity probe and connection to tuned VM HP 302

Shunt capacity to ground through coax and additional capacitor if required

FIGURE 1: Electrical schematic of tower connection and measuring instrumentation

Source voltage consists of VLF power source and coupled-in sources such as atmospherics add LF sources in the area

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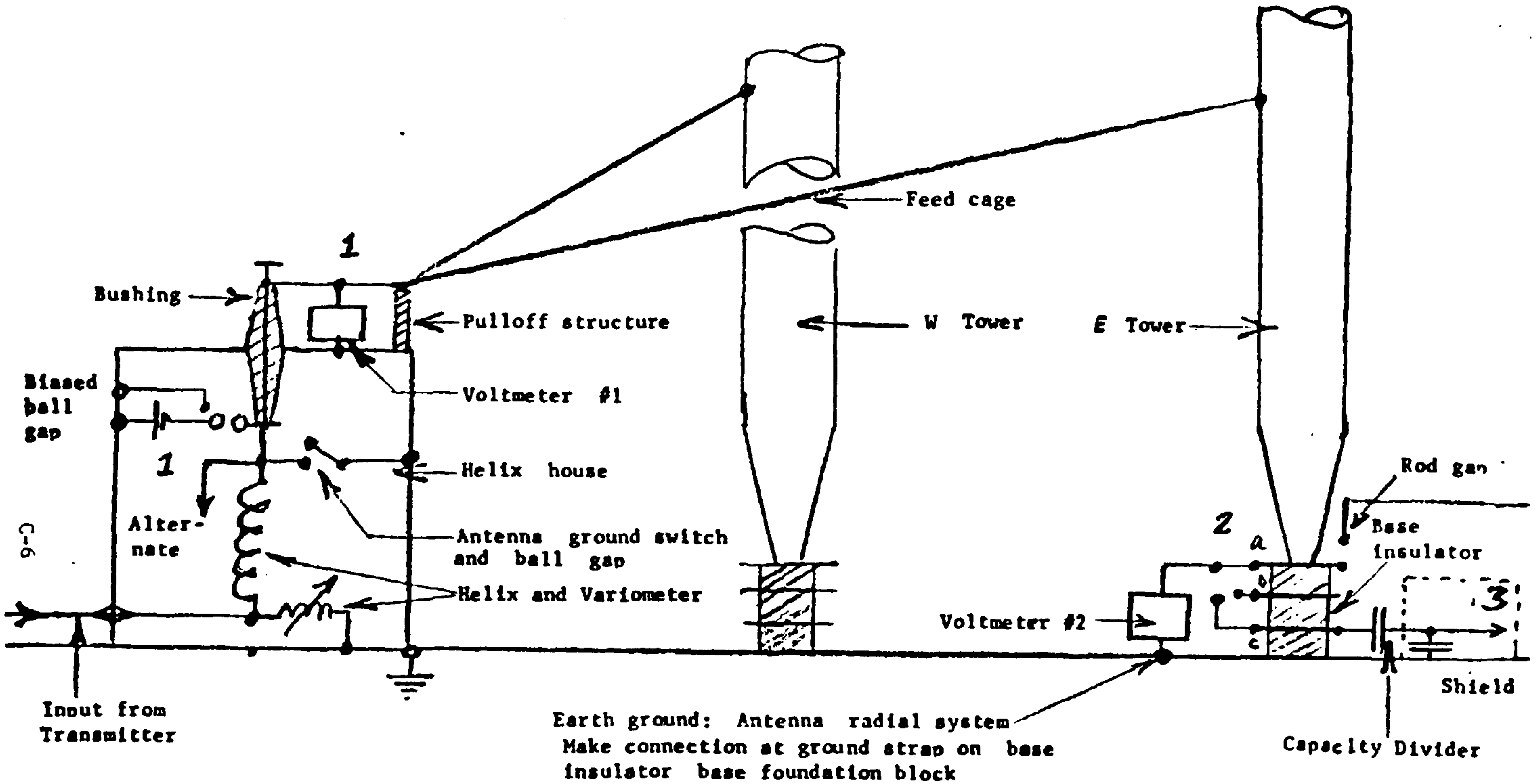

FIGURE 2 MEASUREMENT STEPS 1 +2: Voltage rise and calibration determination

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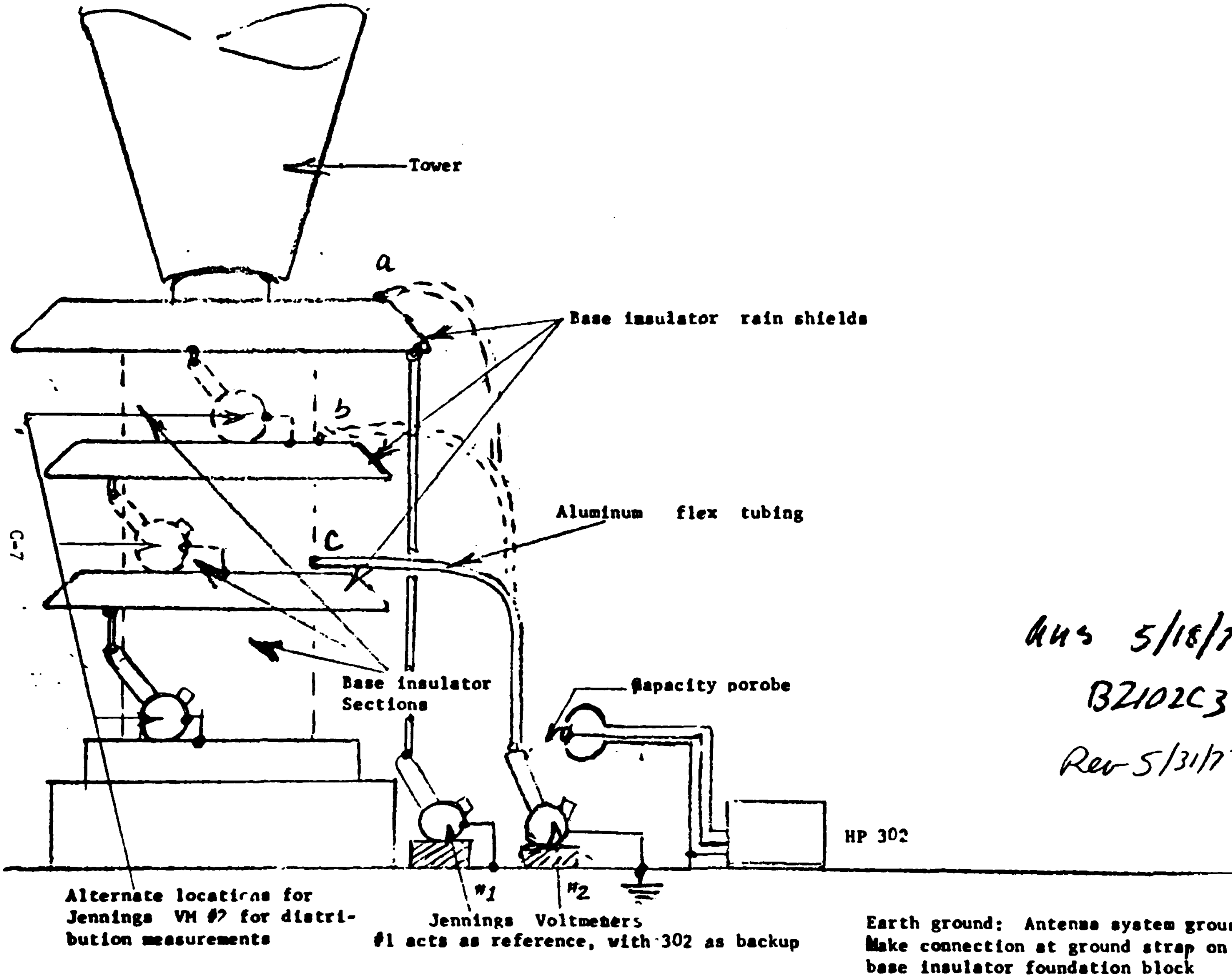
B2102C3

Rev 5/31/72



AHS 5/18/72
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Rev 5/31/72

FIGURE 3: Connection diagram for Step I measurments at tower base

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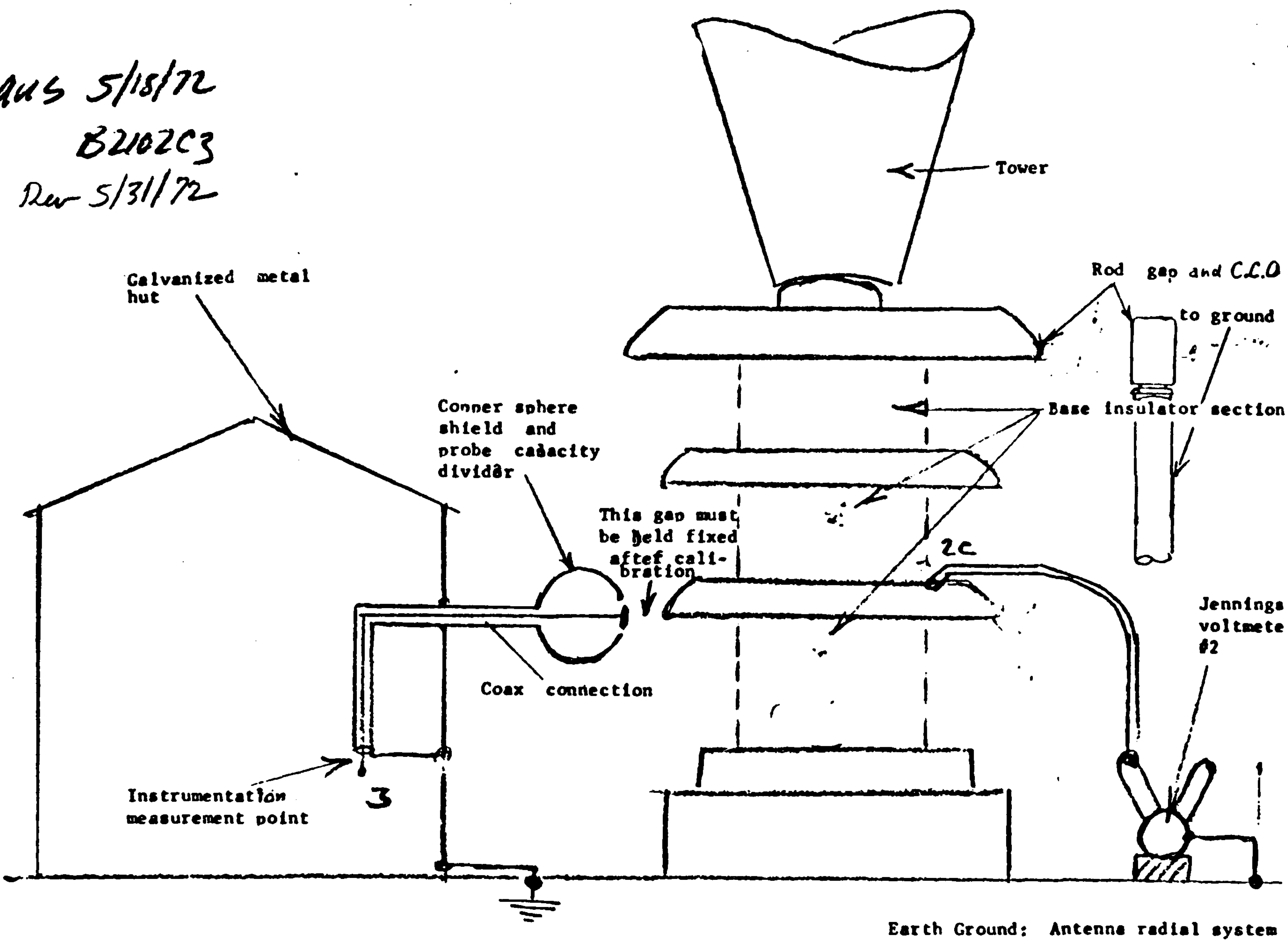

FIGURE 4 : MEASUREMENT STEPS 1 and 2: Calibration and Base voltage measurement; waveform & transi monitoring

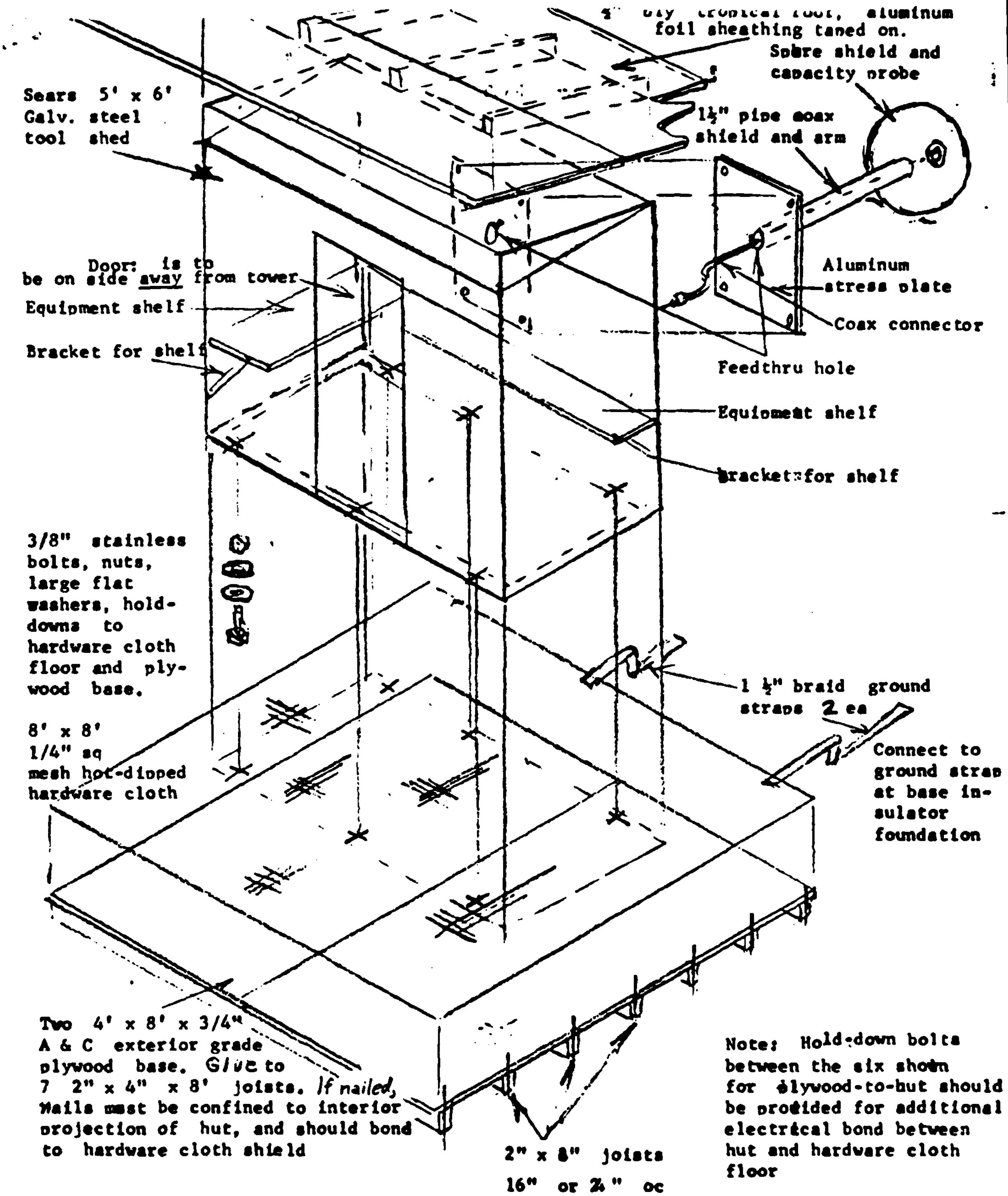

FIGURE 5 : CONCEPTUAL DIAGRAM OF EQUIPMENT HUT FOR USE NEAR TOWER

AKS 5/18/72 B2

Rev 5/31/72

20 April 1972

PROPOSED TEST PLAN FOR ILL

It is proposed to set up instrumentation which will permit Oscillographic recording of the voltage on the tower immediately prior to flash over of the protective gap.

INSTRUMENTATION

1. A capacitance voltage divider consisting of the Top Rain Shield and Tower as one Electrode and a Corona Ring (similar to that being used for the auxiliary gap) as the second electrode with a low voltage (of greater than 0.01) capacitor as the low side of the divider.

2. Two oscilloscopes are required: one of which preferably would be a high voltage surge oscilloscope such as the Tektronic 507, and the other a dual oscilloscope such as Tektronix 555 or 556. One of these oscilloscopes would be set to trigger with a start of voltage on the 20 kHz signal and the other to be triggered by a separate probe in the vicinity of the protective gap.

3. Polaroid cameras could be used to record the traces on each oscilloscope.

PROCEDURE

The transmitter frequency and voltage level and the protective gap setting would be selected such that the operation of the gap occurs at intervals of a few minutes. The camera shutters will be left open continuously and the film advanced periodically at what ever intervals prove necessary to avoid serious fogging prior to triggering of the sweep by the overvoltage or gap operation.

A preliminary series of such recordings with variable sweep speed and gain settings should provide an indication of the nature of the overvoltage (if any) and guide further experimentation to examine the characteristics of the overvoltage in greater detail. A further solution might take the form of using a much longer signal cable than trigger cable in order to permit recording the signal voltage for a longer interval prior to the gap operation; it might include construction of a sensative discrimination circuit for use in shaping the trigger pulse for that same purpose or it might involve the introduction of tuned circuits for filtering.

Dr. Ralph Kotter (NBS)
Telephone 921-3121

APPENDIX C-1

NELC Report
No. 1300-543

TECHNICAL REPORT

OF

VLF TRANSMITTER ANTENNA BASE

INSULATOR FIX INVESTIGATION (U)

Engineering report of measurements and fixes implemented and tested at NRL and Lualualei during 3-21 August 1972

A. N. Smith
Code 2160

16 October 1972

Naval Electronics Laboratory Center
San Diego, California 92152

APPENDIX D

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PROBLEM

Supervise the high voltage measurements and application of proposed quick fixes and tests thereof on the antenna base insulator assemblies of the VLF transmitter systems at NRTF Lualualei, Hawaii.

RESULTS

1. Electrical measurements at Lualualei confirmed previous measurements made at Chollas Heights test bed.

2. Internal corona without pressurization not detected but still a possibility.

3. The applied fixes permit full power operation in fair weather, but until exact method for environmental control and clean-up is determined driving rain constrains operation to 400 kW.

4. Temporary method of partial seal of cones and pressurization of SF_6 is unsatisfactory and hazardous.

5. Cleanliness of interiors poor and base ring drill technique needs changing.

RECOMMENDATIONS

1. Set ball/ring gaps for approximately 80 kV each and external rod gap to 250V wet.

2. Apply all fixes, including environment control and run final series of test to refine fixes before going operational.

3. If similar hollow cones are used in future application, they should be kept clean and dry throughout handling and assembly, but alternate skirted design should be cost traded for application at Annapolis.

ADMINISTRATIVE INFORMATION

Work was performed by members of the Radio Technology Division (Code 2100) during August 1972.

INTRODUCTION

HISTORICAL BACKGROUND

Two of the Navy's primary high power VLF transmitting facilities at Annapolis, Maryland and Lualualei, Oahu, Hawaii are presently not operational because of high voltage arcing problems at the bases of the antenna towers and in the transmitting circuits. NELC has been tasked on a priority basis to assist in solving these problems, both by carrying out experimental tests on fixes in the field and by acting as NAVELEX consultant in Ad Hoc committee meetings taking place on a regular basis with contractors and other government agencies concerning progress in arriving at solutions. Initial studies for this effort were completed in July 1972. Definitions of insulator fixes at both VLF transmitting sites has been completed in August 1972. NELC has designed and constructed a test bed at the Naval Radio Transmitting Facility, Chollas Heights, San Diego, California for initial experimental testing of the proposed "quick-fixes." This test bed included a concrete pad, stand for insultators, and rain shield mock-up. Investigative tests were then conducted during the period 1-10 July 1972 at Chollas Heights. These tests were for the onset and extinction voltage for corona detecting devices: UV detector and carrier cut-off and ozone detector. Based on the results of these preliminary experiemental tests, further tests were required to be performed at Lualualei of some of the configurations investigated.

STATEMENT OF THE PROBLEM

Supervise the high voltage measurements and application of proposed quick fixes and tests thereof on the antenna base insulator assemblies at the VLF transmitter systems at the Naval Radio Transmitting Facility (NRFT), Lualualei, Oahu, Hawaii.

SCOPE OF THE INVESTIGATION

Concurrent with visits by representatives of the Naval Electronics System Command Headquarters (ELEX -05), NAVSEEACTPAC, ROICC MIDPAC, NCEL, CHESDIVNAFACENGCOM and contracted engineers from Maxwell Laboratories, Hy-Power Electronics, Lapp Insulator, Westinghouse, Leesburg and Consultec, Inc., Mssrs, Andrew N. Smith and J. C. Hanselman of the Naval Electronics Laboratory Center visited NRTF, Lualualei during the period 3-21 August 1972 to perform the supervision indicated in the statement of the problem.

SUMMARY OF MODIFICATIONS APPLIED

Figure A illustrates the insulator modifications to be applied, tested, and evaluated. These were:

a. NELC modified extended rain shield for protection and voltage distribution improvement.

b. Ball/ring intratier arc gap.

c. Westinghouse capacitor pickup electric field balance sensing carrier cut-off (CCO) modification.

d. Temporary partial seal of cones and pressurization of SF_6.

e. External rod gap calibration and resetting for wet flashover at rated voltage.

f. Cap and ring field shaping rings designed by Maxwell Labs. for local gradient control.

g. Environment control and clean-up.

METHODS

INVESTIGATIVE TECHNIQUES

The NELC team arrived at NRTF Lualualei on 3 August 1972. Preliminary conferences were immediately held with station personnel, Westinghouse, NAVSEEACTPAC and ROICC MIDPAC reprsentatives relative to the tentative schedule of events and material support requirements.

CONCLUSIONS

a. Electrical measurements at Lualualei reported in NAVELEX letter ser 2100-276 confirmed, and measurements at Chollas Heights confirmed.

b. Internal corona without pressurization is still a possibility but was not detected although test may be inconclusive.

c. Modification fixes a through f (summary of modifications applied paragraph) permit full power operation in fair weather, but in driving rain safe power level to prevent excessive corona flaring may be down to 400 kW.

d. Fix g will be necessary to permit full power operating in wet weather, but the exact method for insuring dry environment for cones and interior ball gaps has not been determined.

e. Temporary method used for sealing involving application of silicone grease over calking is not satisfactory, and with SF_6 leaking out into wet and ionizing environment pressurization may be hazardous.

f. Cleanliness of interiors poor and technique used for drilling base rings needs chaning to avoid scattering of metal particles on cones of center tier if base rings are to be drilled.

g. Skirted type porcelains would be preferable in this application if cost competitive.

RECOMMENDATIONS

a. Apply all fixes listed below, including environment control for providing dry warm air for cones and intratier ball/ring gaps dry.

b. Set ball/ring gaps for approximately 80 kV each, and external rod gap to 250 kV wet.

c. Run final series of tests to refine fixes before going operational.

d. If the future similar hollow cones are used in the application, they should be kept clean and dry throughout handling and assembly, but alternate skirted design should be cost traded for application at Annapolis.

APPENDIX A - SEQUENTIAL CONDUCT OF INVESTIGATION

8 Aug 1972 Started interference voltage measurements E tower, reconfirming grading and calibration. Started modifying Hy-Power Electronics' interior corona detecting device to "look" toward top cap.

9 Aug 1972 60 Hz calibration comparison made of all Jennings Voltmeters. Conference with LCDR Hull relative to progress and schedule and writing of daily test plan by Westinghouse. Holes completed to interior of numbers 1, 2, and 3 cones E tower (see enclosure (2) for numbering scheme). Initial visual inspection carried out and conducted test with Hy-Power corona detector for discharge presence under voltage. Based on visual determination with borescope of extensive drill chip scatter, decision made not to drill base rings of inverted cones. High intensity fiber optics borescope ordered for further visual inspection.

10 Aug 1972 Tests wet and dry of flashover and corona inception conducted on one section of station posts under diesel unit at W tower.

11 Aug 1972 Discussion with Holmes & Narver Inc. representatives on relative price and safety factor for North Dakota OMEGA base insulator for application at Lualualei and Annapolis indicates that vertical load factors are not quite adequate although shear loads are. All holes in top and bottom tiers E tower complete, 4 at W tower complete, inverted cone caps not drilled. Test of corona inception internally with Hy-Power device on all upright cones E tower gave negative results but inconclusive because of doubts concerning sensitivity of detector. HiPot test of ionization E tower inconclusive.

12 Aug 1972 Completed drilling upright cones W tower. Westinghouse CCO balance modification circuit installed and successfully tested. West tower, Corona inception tests performed dry W tower showed various problems similar to E tower

down to 98 kV levels, additionally there is corona on sharp edges of bolt ends. Test for interior corona conducted all upright cones W tower gave negative resuls up to 142 kV tier. Measurement of antiresonances looking back in across tower base insulator failed due to loading of source on parallel resonant circuit.

13 Aug 1972 Sunday.

14 Aug 1972 Remaining inverted caps drilled. Detailed inspection of all upright cones both towers carried out by NELC and some of the cap interiors, using high intensity fiber optics borescope. Photographs taken of some interiors and some caps. Cleanliness of bases, porcelains, and caps highly variable, including some evidence that splashed grout on surface of #9 E was never wiped off.

15 Aug 1972 Detailed inspection of cone interiors carried out by Westinghouse independently of NELC. A decision was mde to complete attempt at sealing and pressurization before proceeding with more high voltage tests. Resonant rise measurements made on E and W towers from within combiner room checked computer calculations. Installation of NELC mod rainshield complete W tower and grading measurements complete. Ball/ring gap installed E tower, leakage tests after temporary sealing and pressurization complete. Moved to E tower to run wet and dry corona inception tests with top ring field shaping devices installed on top tier only.

16 Aug 1972 Held conference with all concerned on status of tests and in conjunction with Westinghouse generated test plan for final period to end of week. Bottom field shaping rings mounted on top tier, E tower, NELC mod rainshield mounted E tower. Ball/ring gaps installed W tower. Repeated test of sensitivity of Hy-Power corona detector, indications are that this would be adequate but that leakage of rf field into the circuit and into the light sensitive diode biases the system and reduces sensitivity. NELC UV corona detector also shows the same susceptibility to rf fields. Set up for dry flashover test of top tier of E tower and discontinued test upon observing extensive corona on the outer edge of lower

AD-A102 473 ELECTROSPACE SYSTEMS INC SAN DIEGO CA F/G 9/5
HISTORICAL REVIEW OF VLF INSULATOR TESTS.(U)
JUL 81 A N SMITH N62583-81-MR-302

UNCLASSIFIED CEL-CR-81.020 NL

3 OF 4
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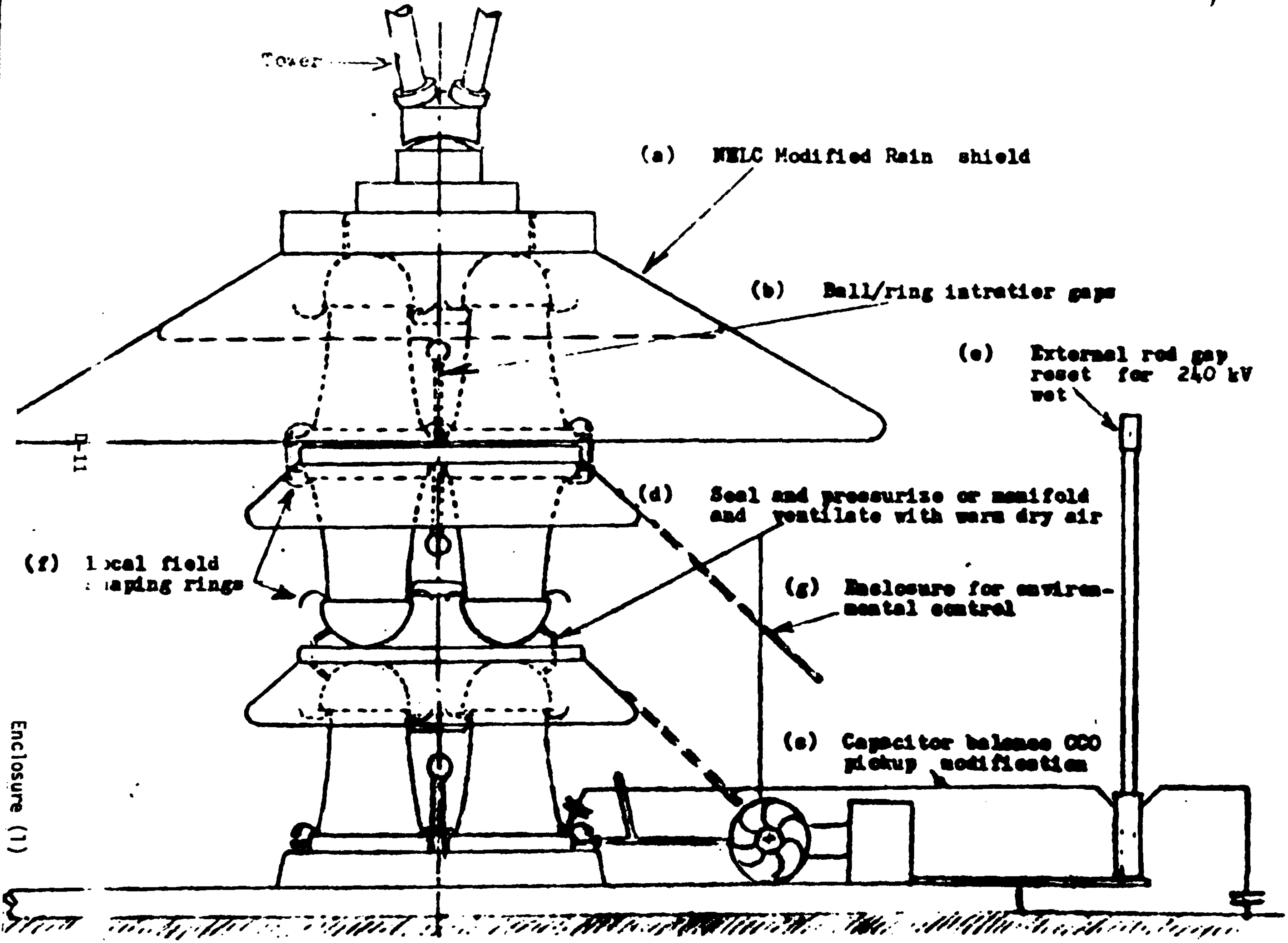
field shaping rings, indicating that edges should be rolled.

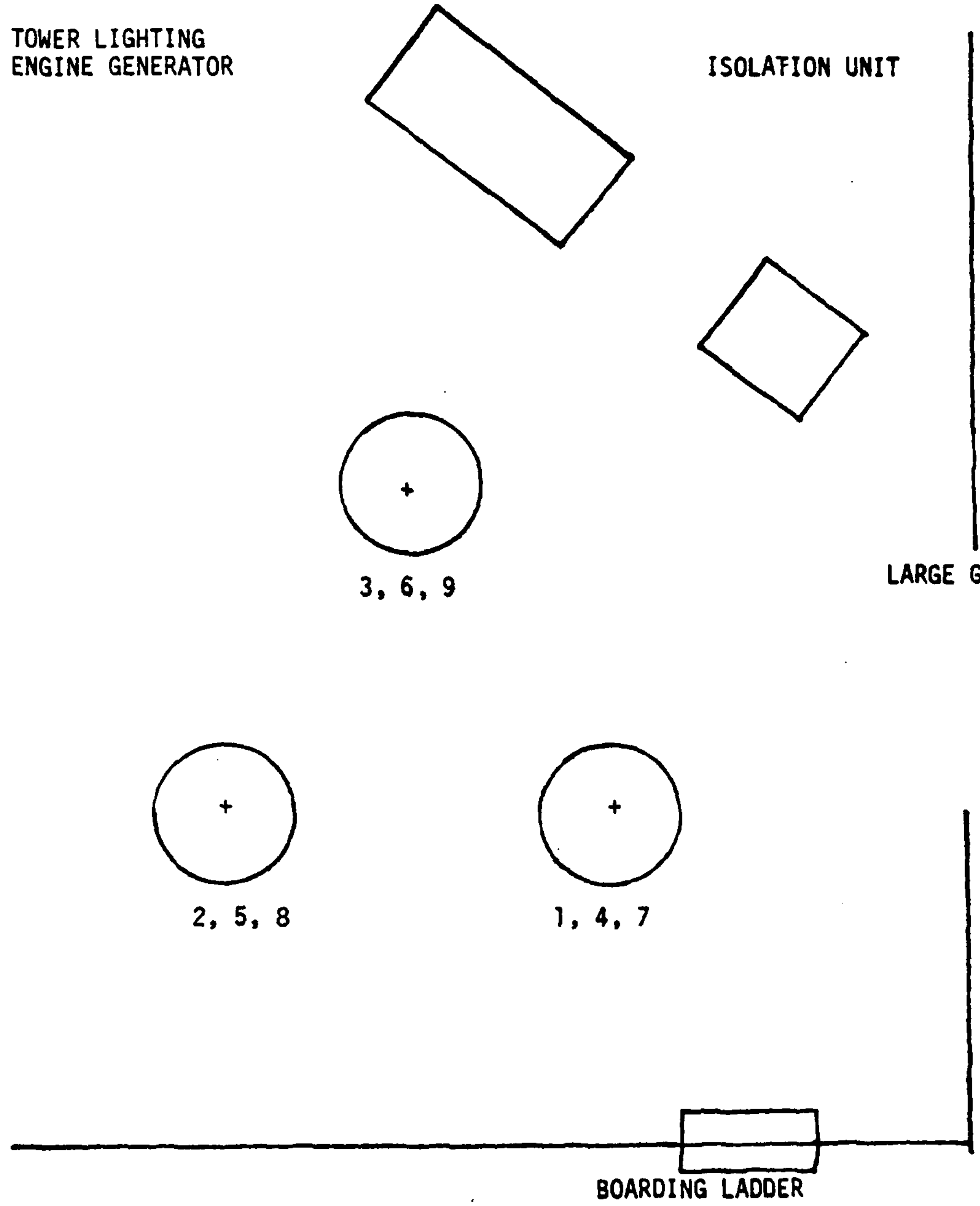
17 Aug 1972 Botton field shaping rings removed and modified by addition of flex tubing for rounded fairing.Carrier Cut-Off (CCO) device installed and successfully tested E tower. Completed installation of ball/ring gap W tower. Observed and photographed SF_6 gas bubbles in DC-5 filler around center tier caps, E tower, units No. 4, 5, 6. Tested top and middle tier E tower for dry flashover, dry corona inception, wet corona inception, wet flashover with and without ball/ring gaps in place. Tiers tested separately and in cascade. Performed dry flashover test of one and two station post sections under diesel-electric plant E tower with and without electrostatic rain deflector.

18 Aug 1972 Ran calibration of Westinghouse rod gap dry and wet, E tower. Performed partial check of grading with bottom tier strapped, dry. Performed dry and wet flashover with top and middle tiers in cascade and wet test with entire unit active. Observed arcing and burning phenomena and subsequent etching of glaze near bottom of #5 E, attributed to chemical reaction with dissociation products of SF_6 in presence of water and ionization. Ball/ring gaps arced in cascade with CCO modification active. Attempted dual tower operation at full power, succeeded in getting up to approximately 900 kW. Wet flashover and wet corona (spray). Test with standard water indicated that in presence of NELC modified rain shield top tiers operate nearly dry, and grading is greatly disturbed. With only 130 kV on E tower base insulator, extensive corona was observed on surface of units No. 2, 5, and 6; although the flashover voltage wet was initially 190 kV, this progressively dropped to the lower value.

19 Aug 1972 NELC team held final brief conference with LCDR Tatom and CWO Knapik and Hagaman, Morrison, and Milbourne on tentative results and conclusions. Discussed probable cause of etching of porcelain and significance as to structural integrity with D. Fiero, Lapp Insulator Div. Conclusion was probably no significant weakening of unit.



BASE INSULATOR SHOWING APPLICATION OF FIXES



NUMBERING SCHEME FOR INSULATOR UNITS IN BOTH TOWERS

Bottom deck, 1, 2, 3
Middle deck, 4, 5, 6
Top deck, 7, 8, 9

PERSONS CONTACTED IN

CONNECTION WITH PROGRAM, L^3

RTF L^3

LCDR C. Tatom

LCDR C. Lewis

LT L. Murch

CWO P. Knapik

ETC Richardson

ETC Richardson

L. V. Foster

NAVSEEACTPAC

G. Uedoi

V. Burch

ROICC MIDPAC

LT E. Fucille

CHESDIVNAVFACENGCOM

LCDR D. Hull

Maxwell Labs

Dr. C. Richards

HY-Power Electronics

N. C. Matlack

NCEL

J. Norbutas

NAVELEX 05

F. Seyfried

Lapp Insulator

D. Fiero

J. Moran

Westinghouse, Leesburg

B. G. Hagaman

W. S. Detwiler

J. Morrison

D. Milbourne

CONSULTECH

C. J. Pitt

BASIS FOR LUALUALEI HIGH VOLTAGE TEST CIRCUIT DESIGN

by

A. N. Smith

8 June 1973

Radio Technology Division, Code 2100
NAVAL ELECTRONICS LABORATORY CENTER
San Diego, California 92152

APPENDIX E

BASIS FOR LUALUALEI HIGH VOLTAGE TEST CIRCUIT
DESIGN

1. GENERAL

SPECIFIED INSULATOR TEST REQUIREMENTS

Frequency	10 - 30 kHz
DFO	475 kV
WFO	400 kV
Withstand, 60 min.	300 kV
Temp rise	$<30°$ C over ambient, at 300 kV
Dry Corona Inception	275 kV
Interruptions	<6 per 12 hours cont. operation, 250 kV

TEST SOURCE VOLTAGE AND POWER

Source must be capable of at least 12 hours continuous operation in all weather conditions of interest for the test object at 250 kV to perform the interruption test, and must be capable of 300 kV operation for a period of one hour for the withstand and temperature rise test. Since this involves wetting the test object only, presumably the 300 kV operation capability of the test circuit is required for dry conditions only, except if the test is once started it should continue uninterrupted for the hour duration regardless of change in the weather. The source voltage must be held within about 1% of nominal during any condition of extended test, which means that if power requirements vary as a result of wetting and change of leakage resistance across the test object during the process, the source must sustain the output without regulating down.

Additionally, the source must provide for controllable output in a ramp rise fashion during flashover tests from 300 kV to 500 kV and for corona inception tests from a minimum of 250 kV. For calibration procedures, the source voltage should be controllable down to 50 kV. Instantaneous shut-down capability is also required.

By previous test results from Chollas Heights on fog-type insulators, the leakage resistance under spray wet conditions can be expected to go as low as 1 to 3 Megohms, in overvoltage ranges from corona inception to flashover. Accordingly, for withstand tests the power requirement can be expected to be of the order of $(3 \times 10^5)/10^6 = 90{,}000$ watts as a minimum; during flashover tests the demand can be in the range 160 kW to 250 kW. During the tests considerable variation can be expected, and the matching circuit of load to source must be able to accommodate the changes. Impulsive change in matching conditions when the load goes from dry to wet conditions as a result of spray application must not result in undesired activation of safety overload protective devices.

ENVIRONMENTAL CONDITIONS

Temperature ranges expected are 50°F to 100°F, relative humidities from 40% to 100%, winds to 50 mph, blowing dust. Normally the circuit may not be required to operate in rain although operation in light blowing mist is a possibility. Accordingly, the components must be designed to be corona free in these conditions, have the appropriate radii of curvature to remain below critical gradients for these conditions up to the full operating voltage anywhere

in the circuit, be of weatherproof material, i.e., porcelain fog type insulators, PVC-jacketed litz with water tight joints and end fittings, and the structural design must be such as to meet expected cantillever loads due to wind drag forces.

CIRCUIT ANALYSIS

Ordinarily at power line frequencies high voltage insulator tests are conducted with a source consisting basically of a high voltage transformer for which no effort is used to tune. Impulse withstand tests are conducted with the aid of a high voltage shaped-pulse generator such as a Marx generator. In one installation where the test objects are high KVA reactors, a tuned circuit is used at power line frequencies, but this is not usual. At VLF, on the other hand, the economics of the circuit almost demand use of a tuned circuit.

Figure 1 is a simplified equivalent of the test circuit, in which R_s is the shunt resistance offered by the test object and C represents its capacity combined with other elements in the circuit. There is no circuit in which the capacity will be less than the order of 200 to 300 pf as a minimum. The insulation resistance will be of the order of 10^9 ohms or lower, depending on surface conditions, although without regard to surface contamination the resistance of the porcelain itself is several orders of magnitude higher. The high voltage is supplied by a coil L_s which may be link coupled to the primary, or may be in the form of a tapped inductor directly connected to a matching circuit, such as the autotransformer in effect used in present day VLF station helix houses. While tuning is not mandatory in principle, the most economic outcome is obtained if the circuit is tuned, since then the highest voltage point appears in coincidence with the terminal connection of the coil to the capacitor. If this is not so, then the high voltage point appears within the coil (for a situation where there is "too much" coil for the capacity being used) so that part of the coil is being used to cancel the excess capacitive reactance. Since under these conditions the number of turns to the point of highest voltage in the circuit is less than the total available, the effective series induced voltage is not producing the highest evident terminal voltage that would be possible if the entire coil is used. If the coil is too small, on the other hand, the same discussion applies except with regard to some portion of the series capacity to some interplate medial plane in the capacitor structure, and again the highest voltage point is not available at the coil ends, where the connection of the test object is made.

Assuming a tuned circuit, Table 1 has been constructed for pairs of capacitor and coil to tune to a mid-VLF frequency 20 kHz. One can readily see that the range of interest from the standpoint of practically realizable components is toward the bottom of the table, for capacity above the order of 1000 pf and coils smaller than 64 mHy.

Another aspect of importance that limits the range of circuit parameters is the necessity of maintaining some kind of reasonable impedance match to the power source. The economic limits imposed on most generators during design severely limits the range of impedances they can match. The table shows the effective series resistance presented to the circuit for the typically wet and dry conditions for the insulator, and it is evident that although the order of magnitude change is the same for each pair of conditions regardless of circuit reactance, the absolute magnitudes of the effective series loss for wet conditions for the low impedance circuit (small coil and large capacitor) reduces to something

of the order of circuit losses already present as the reactance decreases. Thus the change from dry to wet conditions on the test object makes much less relative change in the total losses for the low reactance circuit than for the high reactance circuit, resulting in less impulsive change in matching conditions for the source. For this reason also, the reasonable lower limit to test circuit capacity at the VLF frequency of the example appears to be of the order of 2000 pf, since the test circuit resistance will be of the order of a few ohms under dry conditions.

Finally, as a matter of convenience in setting up the circuit components, initial tests of the circuit itself will be done in the absence of the test object. Therefore, the object must represent a perturbation in the circuit parameters within the convenient capability to handle the change. This can be done if the change is 10% or less. The expected capacity of the insulators under procurement is about 140 pf, so on this basis the total circuit capacity will be of the order of 1400 pf.

L AND C TRADE-OFF VS FREQUENCY

With the above order of magnitude limits in mind, and anticipating somewhat the selection of conductor in the inductive part of the tuned circuit, which will limit current-carrying capability to the order of 200 amperes, one can construct Table 2. The 19.8 kHz portion of the table is seen to be a "fine structure" cut of a portion of Table 1 with the additional requirement that the circuit resistance has been selected so as to represent an upper limit for a power drain of 100 kW maximum. While this is not an absolute condition since at Lualualei the power capability of the transmitter there is substantially higher, it does serve to flag the upper limit of tolerable circuit loss, even under wet conditions on the test object, for the 500 kV required test voltage. In other words, in this table, if the transmitter driving the circuit can deliver no more than 100 kW, and if during wet conditions a flash test must be conducted to 500 kV, then the total circuit resistance must be less than the values indicated or else the circuit will "hang-fire" and the flash cannot be obtained. Obviously, for the same current and voltage, as the power available goes up, the allowable resistance rises also. The situations corresponding to what can more or less realistically be realized for available sources and economically viable components under the 100 kW restriction are outlined in the boxes in the table. It is readily seen that if the insulator resistance does not fall below about 3 megohms in wet conditions, then the tests can be run with such a source with conveniently sized components in the upper half of the VLF range. If the insulator in fact goes to 1 megohm, then the power requirement rises to at least 300 kW, and to keep the circuit components within reason the frequency preferred will be near the top of the range. In fact, with about 400 kW, 1800 pf, 28.5 kHz, and about 18 mHy, the impulsive change in circuit resistance in going from dry to wet conditions is less than the allowable total of about 12 to 16 ohms, that the source can supply at this power level. Since it is likely that the dimensions and configuration of the test object will be such as to prevent the shunt resistance from ever actually going as low as 1 megohm, selection of circuit parameters in this range should assure that all conditions of the tests can be run using the Lualualei transmitter as the source.

Another aspect favoring the choice of frequency at the top of the range is that for fixed capacity and current (voltage), the coil size requirement decreases as the square of the frequency increases. Thus a selection at the high end of the range can lead to a substantial savings in material cost for the coil compared

to selection lower down. Since inductance is proportional to the square of the number of turns for the same coil dimensions, and is inversely proportional to the square of frequency, the cost of the conductor is inversely proportional to frequency. Finally, it is known from experience that coils in the range of 10 to 20 mHy for VLF are practicable to construct and still attain a reasonably high current carrying capability.

APPROXIMATE CHOICE OF L AND C

At this stage it is appropriate estimate what a capacitor of the order of 2000 pf and a coil of the order of 15 mHy will look like. As a start, we consider a parallel plate capacitor which must safely withstand 500 kV. It is known from many experimenters that the critical gradient for corona formation in air at STP is 2.35 kV/mm,* under dry conditions. If a surface is in its usual state of roughness and oxidation from exposure to outdoor conditions, a fair estimate of decrease in E_c is about 20%. The degradation in onset level in going from power line frequencies to VLF is 10% to 15%. Allowing for atmospheric density decrease from elevated temperature of heights or barometric changes up to the equivalent of 4000 feet above sea levels indicates a pressure factor of about 5% decrease. These figures and their determination are discussed in references 1 through 6. It has been further found that an atmospheric density reduction of about 40% may be applicable for very damp, but not dripping wet conditions. These factors are represented by the symbols M, F, K, and D and are accordingly 0.8, 0.90, 0.95, and 0.6. Finally, for field concentrations either due to edge effects or protuberances such as raindrops during wet conditions, a reduction of 50% might reasonably be applied for long-term withstand. The combination of all these factors applied together to the original figure of 2.35 kV per millimeter results in a limit of 0.47 kV per millimeter for critical gradient under the worst combination to be expected. Thus, a plate separation of 500/0.47 = 1060 mm would be required for safe operation corona-free under all conditions for a parallel plate capacitor carrying 500 kV. The plate area would accordingly be

$$A = C\, d/\varepsilon_o \cong 2000 \times 10^{-12} \times 36 \times 10^{9} \cong 225 \text{ m}^2$$

or 15 meters on a side. If the plate were 2 meters off ground, then the dimension would be 20 meters square.

The above estimate ignores treatment of the edges, which after being suitably rounded for gradient control will themselves contribute substantially to the total capacity. The relationship for critical gradient and voltage for a concentric cylindrical capacitor or its cylinder-over-a-plane equivalent is displayed in Figure 2. Using the above factors for gradient reduction, it is readily found that a conductor 0.15 m (6") radius two meters over the ground will withstand 500 kV. If used as the edge of a parallel plate capacitor, it will have the capacity calculated by the formula of Figure 2 reduced by half because of mutual shielding due to the presence of the interior plate. Accordingly 80 meters will contribute

$$C = 2\pi\ \frac{10^{-9}}{36} \times 40 \times \left(\log_e \frac{2 \times 2}{0.15}\right)^{-1} \text{ fd} = 670 \text{ pf}$$

An exactly similar capacitor 17 meters on a side will provide 1950 pf due to

*A.C. rms

the combination of edge effects and the flat plate, and in this case about 30% of the total is from the edges alone. In the absence of the interior plate, the capacity would be twice the contribution of the edges, or 2 x 570 or 1140 pf for a total run of 102 meters of conductor. This figure makes a structure composed of a number of horizontal and parallel busses look attractive, since for 2000 pf six 100-foot long trunks of 6" radius and two meters off ground, and separated by fifteen feet would suffice. (It should be noted that if built so that there are free ends, the above approximate analysis would not apply since there is change concentration and hence field enhancement at the free ends by approximately 100%). Table 3 has been constructed for various choices of dimensions assuming that operation in dripping wet conditions will not occur, i.e., the additional 50% reduction would not occur. Also, account has been taken of the contribution of the second term in the expression for corona-free gradient, assuming atmospheric density of 0.95. The 2000 pf capacitor can be constructed from 164 meters of 0.1 m (4") radius buss located 5 meters off the ground, for example (if built so there are no charge concentrations at ends or corners). Figure A-1 is a curve of h vs a for M x F x K x H = 0.5.

An equivalent configuration would be a concentric cylinder with outer radius the same as twice the height over ground. Thus, interpolating in the last pair of entries in Table 3, we see that a capacitor 300 feet long, with a center conductor about 10" in diameter and an outer radius of 10 feet would also suffice. However, there are evident structural and construction complications.

A similar calculation for a hypothetical concentric cylinder capacitor sealed and pressurized with SF_6, first at atmospheric, and then at one atmosphere gage, pressure yields results listed in the bottom half of the Table. While these look attractive at first, consideration of the feed-through bushing arrangement and the cost of SF_6 reveals that there would be little cost advantage in such construction over that of the air capacitor consisting of parallel trunks.

To further define capacity realizable from structures put together to minimize end effects, an extensive series of measurements was carried out on 1/33 scale models. The measuring instrument was a Boonton 260A Q-meter, which gives very accurate determinations of capacities of the order of 100 pf. The configurations studied are shown in the top half of Figure 3. From these generalized configurations could be constructed capacity values for other structures using a modular concept. These are shown in the lower half of the figure. From preliminary contact with suppliers, rough figures were obtained for major components in the capacitors, again on a modular concept, and price comparisons as indicated in these diagrams were then available. The rough price figures are given in Table 4. The installed rough price for a capacitor having 1800 to 2000 pf and 500 kV withstand appears to be in the range $15,000 to $20,000 of which about half would be material costs. Since cost appeared to be in rough proportion to size, although a larger capacitor would be electrically desirable, the installed price quickly gets out of hand.

The corresponding range of inductance is 17.2 mHy to 15.6 mHy, of which 4.2 is already available in the helix house at Lualualei. This leaves 11.5 to 13 to be provided, or slightly more if the capacity is reduced somewhat. Both because of some savings available by reducing the capacitor size and because a voltage division such that no more than 125 kV residing on the downlead connection from the bushing to the external coils would be a favorable outcome in view of available insulators for downlead support, a selection toward the higher of the figures for

inductance is indicated. Accordingly, a preliminary selection of the pair 1800 pf and 17.2 mHy was made. The cost of the coil to the project is not nearly so sensitively related to size as is the case for the capacitor, because a major cost item is available as pre-expended from another project. This is the litz wire. The coil form components are the same in number almost regardless of the coil size, so that this cost item does not vary much with size. Thus the limit in capacity is defined by the matching considerations discussed earlier, at the lower end of the range, and almost strictly by cost of the circuit, the variable part of which is mostly that of the capacitor, at the upper end of the capacity range. Frequency is selected on the basis that it should be as high as possible.

2. DETAILED ELECTRICAL CONSIDERATIONS

INDUCTOR

As a first approach to providing a coil outside the Lualualei helix house to extend the inductance available to tune approximately 2000 pf, it was assumed that ceramic coil frames taken out of the OMEGA Navigation Station at Haiku during its reconstruction would be available. Calculations of inductance were based on the formulas and Tables in Grover (reference 7). These are summarized in Figure 4. The coil dimensions are approximately as given in Figure 5, lower half, except that the litz actually used at Haiku was 5/8" diameter while that assumed to be available at NELC for this purpose is 1". The frames consist of flanged circular cyclindrical ceramic center forms, shaped much like very short sections of cast concrete water pipe. Projecting from these are ceramic brackets with pads for holding the cable; five of these brackets are arranged radially from each section of the central column formed by the flat cylinders and are held in place by the tension of the cable itself. The structure is sketched in Figure 5. All that would have been necessary to permit use of two or three such assemblies on the pad west of the helix house used in the February capacitor tests would have been to design an insulating support base so that the coils were supported above the ground by a distance adequate to provide the necessary insulation to the bottom of the coil, and to add top and bottom turns at the outer edges with cross section radii such as to control surface gradients to levels below corona onset.

Using the dimensions of Figure 5, which represent the coils as they were configured at Haiku, the inductance available would be 12 mHy per coil. If two were used, then neglecting mutual coupling the total from them and the helix house would have been 28.5 mHy, so that (4.5/28.5) x 500 kV would be the voltage across the indoors assembly with 440 kV outside, or 220 kV per coil. With the top-to-bottom length of 5 feet, this division would not be safe. Several alternate arrangements are possible, for example three similar coils with reduced number of turns so that the total inductance would remain about the same (to keep capacity up to a reasonable value). This would reduce the voltage per coil to about 147 kV. The number of turns per coil could be further reduced so as return the total inductance to about 17.5 mHy so that 375 kV would be split across 3 coils, or 125 kV per coil. This is reasonably related to the 5' coil length, at least for fairly dry conditions. Keeping the same shape factor, the required number of turns would be $N' = (128)(4.5/12.0)^{1/2} = 69$ turns, where 128 is the number of turns on the original 12 mHy coil, and 4.5 is the new required inductance per coil. The pad on which they would be mounted is 30' long with 130 inches between each mount center, so that there would be about 4 feet air space intervening between hardware on adjacent sides of neighboring coils. Since they are offset vertically because of the increasing insulation requirements at the bottom of each, the

voltage gradients in air between coils are probably tolerable. However, the roughly 12 foot distance from the high voltage coil to the helix house face is insufficient to safely withstand the 500 kV, so the last coil would have to be moved to a new pad farther away. The layout is shown in Figure 6.

These particular coil frames proved to be incapable of accepting the 1" diameter litz available at NELC, having been designed for at most 3/4". An alternative frame set still located in the old TCG helix house at Haiku has brackets with the required pad size, but there are only enough to make up two coils with 7 double bank pi's of 9 turns per layer, or 126 turns per coil. With a reduced number of turns to make coils of about 7 mHy instead of 12, two 97 turn coils would suffice, but there would be about 188 kV per coil, and again this is unsafe.

Consideration was therefore given to constructing a coil frame offering approximately this amount of inductance per coil, but with the structure spread out over sufficiently more insulating distance that the gradients along it are safe. The concept developed finally was to use fog-type station post insulators at the apices of a regular polygon, so that the petticoats and the slots between form the coil hangars. This concept is also illustrated in Figure 5. The posts within the coil itself are assembled by fiberglass-wrapped epoxy-cemented joints so that the metal and caps are eliminated. This is necessary because induced circulating currents would cause excessive heating, being tightly coupled to the solenoid current and hence large.

As a first approach to this second concept, it was assumed that three coils would be wound on each of a set of four columns of station posts set up on the existing anchorages on the pad west of the helix house. Such coils would have cross section areas the equivalent of a circle roughly two foot in radius. Typical station posts used as coil forms would provide a solenoidal structure with individual turns spaced about 2.2" apart. Assuming 100 turns, this coil would be about 18 feet high. Calculation based on these dimensions in the formula in Figure 4 and the tables of Grover gives a total inductance of 7.4 mHy for the three which is insufficient. Moreover, on the highest voltage coil there may be corona on the outside corners of the turns where they bend around the posts.

A second approach uses three such coils and the same station post anchorages but adds two new columns to each, making a hexagonal cross section. The result is to roughly double the inductance per coil, which is more than the minimum needed. Reducing the number of turns by appropriate shortening leads to 12 foot high coils of 67 turns each with effective radius of about 3 feet and the total of three giving the 7.2 mHy, and the voltage is divided down to 100 kV per coil. This is actually wasteful of structure material and the unfavorable height-to-width ratio makes it hard to brace against wind load. Since the lengths are such that in elevation the coils overlap, there are small distances of the order of 4 feet with nearly 100 kV across them between coils, which is only marginally safe in wet conditions. Again there is difficulty with proximity to the helix house wall from the topmost coil which could have to be moved away to a more remote pad. These and variant configurations are sketched in Figure 6.

Because some new anchorages must be provided beyond those already installed and a new pad must be provided, a return was made to a two-coil concept to minimize additional footings. A single coil concept, Figure 6, was rejected on the basis

of its unwieldy physical size and again the necessity for moving the structure farther away from the helix house than the existing anchorages would allow if only they were used. For example, a coil 10 feet in diameter, 20 feet high, with 110 turns spaced about 2.5 inches would give about 15.2 mHy; 105 turns on the same form would give the required 13.5, although the voltage distribution would be safe on the frame bracing it would be a problem. Shortening the frame would lead to excessive gradient, so that the overall height for successive modifications would have to remain the same even though the width were increased. This would permit a reduction in the number of turns but not yield any saving on structural material. The final two coil concept is sketched in Figure 7. It makes use of two identical 12' dia x 13' high frames mounted 5 and 13' above the ground plane, spaced 21 feet apart (9 feet between adjacent faces less projection of end turn hardware) and respectively 10 and 26 feet from the helix house wall, which is safe. The mountings make some use of existing anchorages, as indicated. The overall heights give insulator column lengths which are safe, as indicated below.

With a choice of wire diameter of 1", a pitch of 156/60 = 2.5, a coil radius of 6 feet, height 13 feet, and 60 turns, substitution into the formula of Grover in Figure 4 gives L = 8.5 mHy. Account must be taken of the mutual effects of the coil and its image, as well as between the two coils. Making use of the dimensions given in Figure 7 in the expression of Grover, p. 219, and carrying through the rather laborious calculation results in 0.3 mHy by which to reduce the self inductance in the first coil because of its image in the ground plane. The second coil suffers a reduction of about 0.1 mHy. The mutual inductance between the two is very small because of the relative angle between the axes and the line joining the centers, but is assured to be less than 0.1. About 60 feet of 4" diameter downlead gives an additional amount of about 15 uHy, from the formula

$$L_d = \ell\ (\mu_o/2\pi)\ \log_e\ (2h/a),\ \mu_o = 4 \times 10^{-7}\ \text{Hy/m}$$

in which the distance from conductor to image plane is about 5-1/2 feet. The grand total inductance is thus about 16.5 mHy in the external circuit and the total including all that is available inside the helix house is 21 mHy. The overallowance for 2000 pf to tune at 28.5 kHz is due to the desirability to operate at times without the test object connected, which will reduce the capacity by about 10%. Also some range of adjustment is permitted in the circuit components in the helix house and when set at maximum values of inductance the bushing and downlead voltage will not exceed 110 kV.

Table 5 gives the details of the tuning capability trades with various combinations of capacitors and choices of helix house circuit parameters. The trades are based on the measured values of inductance in the fixed helix, 1.7 mHy, and the range of variation in the main tuning variometers, about 0.4 to 2.6 mHy. With the fixed helix in the circuit, the inductance range is 17.9 to 21 mHy, and the frequency is 28.7 kHz to 27.2 for 1630 pf. The expected capacity of the test object is about 140 pf, and the capacity of the connector from the high voltage capacitor to the object based on an assumed length of 20 feet and height over ground of 15 feet is about 80 pf, for 8" diameter conductor. The total of 220 pf can be considered contained in the 1630. In this case, one operates the circuit only with the capacitor and test object combined with the fixed helix when the test object and connector are removed one cannot operate at 28.5 kHz. If the capacitor is designed for 1630 instead of 1410 pf, then

the test object and connector add to give a total of 1850. This can be tuned at the test frequency without the fixed helix, but so also can the capacitor by itself, in virtue of the 17.2 to 19.3 mHy range of the circuit using the variometers only. Moreover, with this selection, one can operate without the test object but with the fixed helix in the circuit if this mode appears desirable, and still reach 28.5 kHz. This selection appears to give the highest degree of flexibility.

For coil dimensions so selected, there will appear at most 4.0 kV per turn (variometers at minimum and no fixed helix) or about 1.6 kV per vertical inch of insulating column. Each turn looks at the medial plane between it and the next across 2 kV, and for a conductor radius of 0.5 inch, looking across 2.5/2 = 1.25", the formula for limiting voltage in Figure 2 yields about 20 kV allowable for high humidity conditions. For rainy conditions, 10 kV would still be allowable so that there appears to be an interturn voltage withstand safety factor of five for the worst possible conditions. The wet flashover of 12 feet of insulating column should be at least 400 kV, based on measured flashovers of 125 kV for fog-type posts 26" high, and flashovers in excess of 200 kV for 50 inches. Accordingly the coil length of 13 feet is safe, and the selection of 50 to 60 inches to ground from the lower side of coil #1 and 10 feet for coil #2 across the support columns is safe.

Since the gradient at the surface of a 1" diameter conductor is well above the corona onset level when the voltage rises above 200 kV for spacings to ground from the ends of the coils, some provision must be made for corona protection there (see Figure A-1). One can see from either this figure or from Figure 2 that the selection of a conductor diameter of 6 inches for the top of the first coil and the bottom of the second is conservative for an operating voltage of 300 kV. In fact, for M x F x K x H equal to 0.40 = (0.8)(0.9)(0.95)(0.6) the withstand without corona to a surface 10 feet away should be 375 kV. This will not permit operation under spray wet conditions, however. For a two-inch diameter bottom conductor looking across 60 inches from the bottom of the coil #1, the result is $V_c = (2.54 \times 10^{-2})(2.36 \times 0.4 \times 10^6 \times 1.18)(4.8) = 133$ kV. For the top turn of coil #2, which is to be 8" in diameter, an assumed separation of 15 feet gives exactly 500 kV. This applies to the trunk over the ground plane leading away from the coil to the capacitor, but the portion of the top turn nearest the helix house looks at the corner of the building, not to its face. If this corner is considered faired to an effective radius of 4" either by use of metal flashing or by assuming the double corner acts like a conductor of this radius, then the median plane over to which the voltage looks is 7.5 feet away, and the safe voltage is about 400 kV. To get back up to 500 kV requires a separation distance to the corner of nearly 30 feet. This is the basis for the location shown in Figure 7 for the second coil. The withstands calculated above for the bottom turns of the two coils result in the dimensions of the stands also shown in Figure 7. The second coil has a stand height that gives some safety factor over that calculated for 10 feet. In the detailed design of the conductor mounts account must be made of the concentration of field near the coil ends. In order to maintain radial departure of flux from turns near the end in spite of the concentration and distortion, the end turns must be located at a somewhat larger radius from the coil axis so as to act as guard rings. The resultant overhang lessens the clearance distance between the conductors of the two coils.

CAPACITOR

From the formula for capacity to ground for a single conductor given in Figure 2, it is evident that a run of 20 feet of 8" diameter buss 15 feet over ground (for 500 kV withstand) from the coil assembly to the tuning capacitor will have about 80 pf of capacity. A similar calculation for about 60 feet of downlead 68 inches away from the helix house center rib and made of 4" diameter tubing (the same assembly as was used during the February tests, but located closer to the helix house wall) gives about 230 pf. These two quantities together with the capacity of the test object and the buss connector to it gives a total of 530 pf to be subtracted from 1850 pf to tune the helix and coils, leaving a net of 1320 pf to be provided in the capacitor structure.

The general nature of the layout is defined by the modeling studies mentioned earlier, and based on the modules studies or upon calculations for combinations of parallel conductors over ground, a number of possibilities can be constructed quickly. The formulas for sets of parallel conductors can be derived from the principle of superposition, and the results for six are given in Table 6. A universal set of curves for all reasonable choices of conductor radius a, height h, and separation s is presented in Figures A-2 through A-7. In applying these to a grid where one set of conductors is crossed at right angles by a second set, it has been found empirically that the cross grid acts as if about half of its actual length is totally shielded.

Figure 8 shows a compilation of a number of possible installations calculated in this way. As an example of the calculation, consider #10 in the two-conductor case. Assume 15' station post height, and 8" diameter, so as to have the withstand voltage of 500 kV. If a 20 foot separation module is used, $h/a = 45$, $h/s = 0.75$, and Figure A-3 indicates that the capacity is about 21 pf/m. A length of 60 feet with an effective apparent lengthening to 66 because of charge concentration at the ends gives a total of 425 pf. The cross-arms are calculated as $h/a = 45$, $h/s = 1.5$, because of the 10 foot separation, and for effective length only 20', because of the 50% shielding. Thus they contribute (6.16) x (18 pf/meter) = 110 pf for a total of 535 pf. A 15 pf allowance is made for additional capacity associated with the two sets of grading rings at top and bottom of the insulator stacks, to give the indicated total of 550 pf. All the other examples were done in a similar manner with curves for two, three, or five parallel conductors used as appropriate. The end result is that configurations 12 and 18 are the most promising, with some advantage lying with 18 because of a somewhat more sound configuration from structural considerations for wind drag.

The selection of the station posts required to hold the grid up off the ground is probably more critical than the selection of the conductors or the determination of length and size, because almost any combination of height vs conductor radius is possible, and one can almost surely be found to yield corona-free operation for a specified voltage. To be assured that operation at 500 kV rms at VLF will be possible without interruption, one finds from perusal of manufacturers catalogues that a continuous duty rating of this magnitude requires selection of a unit having about 2000 BIL rating. Such a unit has about 900 kV wet withstand for 10 seconds, or about 1000 kV wet flashover. Continuous ratings are respectively about 0.5 and 0.4 times these values, so that the continuous rating would be about 450 kV. This rating would apply to all weather conditions including pouring rain. Units having such ratings are

of the order of 180 inches high, have about 160 inches flash distance, and around 400 inches of leakage path. An assembly of seven 26" units such as used in sets of four under the platform mounted generator units at Lualualei would suffice. This is consistent with a measured wet flashover of about 200 kV with two such units in cascade. Structural considerations would establish the column thickness but the electrical aspects determine the length, and this would be unchanged regardless of the structural loading.

An assembly of several units to a total length of 15 feet would require a careful look at grading, since typically in a column of insulators the end units carry a proportionally larger share of the voltage. That is, in a column 7 high, it is rare that the distribution is uniform so that each carried 14% of the voltage unless the assembly is between very large and relatively closely spaced plates. Electrolytic tank experiments conducted as background for design purposes on columns of six post units indicate that for the case of seven units a typical voltage distribution under a structure such as being considered might be as follows from top to bottom: 22, 17, 13, 11, 8, 13, 16. It can be seen that if the string were perfectly equalized, it could be effectively operated at 50% above its nominal rating without grading. Correspondingly, if the grading were applied, then if the string were operated at the original ungraded rating a 1.5 safety factor would be available. This safety factor is important to obtain, since all the manufacturers ratings apply to 60 Hz, not VLF, and it is known that in some cases under wet conditions corona and possible flashover can occur at VLF sinusoidal voltages 30% below those for 60 Hz with the same assembly. Accordingly, grading rings whose exact final dimensions have not at this time been determined will be provided on the station post columns.

ELECTRICAL CIRCUIT LOSSES, MATCHING AND BANDWIDTH

The 1" diameter litz is composed of 5160 strands of #36 AWG copper wire. With 60 turns in a 12' diameter form there is close to 2500 feet, the dc resistance of which is 414/5160 per thousand feet or 0.2 ohms. The rf resistance is double this for optimum stranding, which this very nearly is and therefore for two such coils in series the combined loss will be 0.8 ohm. Proximity to images in imperfect ground planes will increase this figure by perhaps 20%.

The loss in the coils inside the helix house was measured to be 0.25 ohm during the February tests.

The capacitor losses are calculated from a formula that relates the distribution of current density entering the ground to the return circuit to the distribution of displacement flux in the air immediately above the interface. This formulation has been given by various authors (refs [8,9,10]). In simplified form it is

$$P_E = \int (\sum_i h_i/\sigma_i) (\omega \varepsilon_o E_z)^2 \, dA$$

in which the h_i and σ_i are respectively the thickness and the conductivity of each layer of material (assumed horizontally stratified) encountered by the current flowing downward to the collecting plate buried in the ground. There is sometimes included a factor that describes effects of current concentration as the flow is collected on individual wires in a parallel wire grid ground plane, but in many approaches this is accounted for in a redefinition in the thickness h. For a grid of very closely spaced wire, i.e., they are at least

as close together as they are buried, and for usual ground conductivity, this correction is not important.

In the present design the return circuit for the capacitor is supplied by the radial antenna ground system buried about a foot in the ground. The cover is a rocky soil of decomposed crushed coral that has a conductivity near the surface of about 10^{-3} mho per meter. It is contemplated that site preparation will involve lightly scraping the surface to get rid of plant growth and covering the bare earth with a membrane of 0.042 inch thick rubber sheet as a plant growth retardent, overlain by a few inches of crushed coral rock. A recent test of a sample of the material indicated that it has a conductivity of about 9×10^{-7} mho per meter. Assuming that no values vary in the horizontal direction of interest, the first term in the integrand for the losses is $[(0.305)/(10^{-3})](1.3) + (0.042)(2.54 \times 10^{-2})/(9 \times 10^{-7}) = 1.5 \times 10^3$. The factor 1.3 accounts for the approximately 4 inches of coral backfill over the membrane.

The mode of variation of the field is given in Figure 2. One can see that for a grid of several conductors the same height over ground and parallel to each other, the field distribution for one is the same for each and the total field can be obtained by superposition. To a fair approximation the losses can then be obtained by calculating the loss for each separate conductor and summing over the number of conductors. In the case of configuration 18, the area of interest is then defined by the length of the conductor and the width such that the field strength and the loss becomes small. For $x = 5h$, $E/E_o = 0.04$, where E_o is the field immediately under the conductor. In absolute numbers, immediately under a conductor the field is 45 kV/meter, while 50 feet away it is about 5 kV per meter and 75 feet away it is 1.8 kV per meter. Assuming for each conductor an area of width equal to the length of the conductor, 80 feet, and a total width of 150 feet, and summing for nine such conductors, the loss formulation becomes

$$R_c = 9 \times \frac{4\, V^2\, (80 \times 0.305)(\omega^2\, \varepsilon_o^2)}{h^2\, (\log_e 2h/a)^2\, (166)^2} \times (1.58 \times 10^3) \int_{-23}^{23} \left(\frac{h^2}{h^2 + x^2}\right)^2 dx$$

in which $V = 500 \times 10^3$, $h = 15 \times 0.305$, $\log_e 2h/a = 4.5$, $\omega = 2\pi 28.5 \times 10^3$ and $\varepsilon_o = 10^{-9}/36\pi$. The reference current is obtained from $V/X = 500 \times 10^3/3010 = 166$ amperes, where $X = 3010$ ohms is the reactance of 1850 pf at 28.5 kHz. The result is 0.51 ohm. Of course this is partially shunted down by the collection of current in the hardware cloth screen that interconnects the covers over the concrete foundation pads for the station posts and connects this to the rest of the pad screens under the coils, but since this area is only a small part of the total, the loss is not affected much. Ground losses associated with fields in the immediate vicinity of the test object will be inconsequential, but these and stray losses from the coils might amount to another 0.1 ohm.

The grand total is thus 0.25 + 0.96 + 0.5 + 0.1 or 1.81 ohm. Of this total, 0.5 + 0.1 = 0.6 ohm is E-field loss in the vicinity of the capacitor and test object. The two components of this portion of the loss are loss from the crushed coral and loss from the plant regrowth retardent cover of reinforced sheet rubber. The latter is 1.18/1.58 of the 0.6 ohm contribution, or 0.45. This latter number is (0.45/1.81) x 100 = 25% of the total loss in the circuit. Therefore, the contribution of the retardent cover forms an important part of the total loss budget. The circuit Q is 3010/1.81 = 1670, so that the bandwidth will be 17 Hz. If the loss due to the rubber sheeting were not present, the bandwidth would decrease to about 13 Hz, and control of the circuit would be more difficult. The total of 1.56 ohms would be easier to match the transmitter to, but for

resistances of this magnitude and the reactance of the circuit, the bandwidth aspect may present the more serious problem.

Since any such calculations are best estimates only, and may be incorrect by 20% to 30%, additional control of loss has been provided in the form of a resistor that can be inserted in the circuit. It consists of a nichrome wire with a water cooling jacket and is planned to be inserted in the circuit between the connection to the main tuning variometers from the base current meter calibrating shunts. At this point in the circuit, with 110 kV at the bushing, the helix house inductor parameters are such that there will never be more than about 5 kV at this point. Therefore insulation of the water coolant feed is not expected to be a problem. The point of insertion was chosen in favor of that between the common ground of the coupling variometers because the effects of raising the return connection back to the low side of the matching network above an earth ground in the helix house is not known. When this resistor is inserted, the combined loss will be nearly 4 ohms, which is substantially more than the matching circuit has been made to handle up to now. It is expected that the transmitter will be to a degree mismatched, but the direction and amount of the mismatch are not expected to be troublesome inasmuch as conversion to a linear mode of operation in the PA's will raise the effective internal losses of the source.

VLF RADIATION

Radiation from this circuit will be small though finite. The usual expression for power radiation capability under a voltage limitation for an electrically small antenna is

$$P_r = (6.95 \times 10^{-13})\ C_o^2\ h_e^2\ V^2\ f^4$$

where C_o, h_e, and V are respectively the electrostatic capacity, effective height, operating voltage; and f is the frequency. Units are MKS. In the present case, C_o = 1850 pf, V = 500 kV, and F is 28.5 kHz. The effective height is somewhat ill-defined but should in no case be larger than the physical height of the main trunk members in the capacitor, or 4.6 meters. Accordingly, VLF radiated power will be

$$P_r = (6.95 \times 10^{-13})(1850 \times 10^{-2})^2\ (4.6)^2(500 \times 10^3)(28.5 \times 10^3)^2 = 8.3 \text{ watts}$$

Distant radiated fields accordingly will be of the order of 100 dB less than those of usual VLF fixed stations at corresponding distances.

High frequency rfi fields cannot be calculated without a knowledge of the spectrål distribution of frequency components in the discharge, but a feel for the expected magnitudes can be obtained from a comparison of the available current moment in the test object when it arcs with those known to be associated with lightning discharges. In a typical lightning stroke of the order of 100 to 1000 meters of vertical length, there may be 10^4 to 10^6 amperes flowing at the peak of the discharge. The current moment accordingly varies in the range 10^6 to 10^9 ampere-meters with lightning. With the test object the current is of the order of 10^2 in an electrical height whose upper limit is the order of 10. The current moment is thus at most 10^{-3} as big as a small lightning discharge, and accordingly VLF and HF rfi fields will be at most 1/1000 times as large as those from lightning, and will actually usually be one or two orders of magnitude smaller. Operation

of the test facility at NRTF will thus be equivalent to the presence of a thunderstorm of the order of 1000 km or 600 miles distant, from the standpoint of local interference to circuits located 3000 feet or more away from the test facility.

3. FINAL CIRCUIT AND INSTRUMENTATION AND CONTROL

Figure 9 shows the final version of the circuit with the rf parameters indicated. The essential instrumentation elements are indicated also in this figure. The base current is monitored with a digital voltmeter connected to a Pearson toroidal transformer coupled to one of a set of three shunts. The shunts can be used provided the circuit current goes above the 700 amp capability of the transformer, though for the insulator tests using the present circuit this is not expected to happen. A console mounted oscilloscope is used in various ways, one being to sample the waveform at high amplification and filtering to detect corona onset. At current levels to be used, the normal panel meter connected through the Weston movement will not provide a useful indication. From the base current and a knowledge of the circuit reactance, which will have been determined by previous calibration of the console repeaters for variometer positions by a process of tuning up to a substitute capacitor at low power level, the output voltage is determined. This is cross-checked by direct reading from a Jennings voltmeter, set up in a capacitive divider arrangement.

The remainder of the test instrumentation is located in a shielded hut located near the high voltage coil #2. A capacitive probe provides a suitably divided signal from which voltage level for arcover in the test object can be determined from the readings on a Hewlett-Packard wave analyzer. The oscilloscope is used as a corona detection device as well as a means for checking on the purity of the signal waveform, i.e., the absence of undesired modulation. At low levels and with a mismatch, the tubes may not operate in saturation if they are used in class C, and the present lack of filtering in the bias supply leads to a modulation of 180 Hz on the signal under some conditions. The rfi meter operating from a filtered and amplified hf (vlf components are filtered) broadband signal also is a means for corona detection, and the pulse counter is offered as a suggested means for detecting the presence of spurious pulses exceeding the level described in the purchase specification as voiding arcover and interruption tests.

Figure 10 shows the control system, safety interlocks, and communication scheme. This is fairly self-evident. The central control is provided by the Test Director, whose physical location is in the test hut. The attempt has been made to make the system fail-safe, so as to minimize personnel hazard from the very high voltages involves in the test circuit.

4. STRUCTURAL DESIGN

COILS

Both dead weight loads and wind loads must be considered in selecting components for the coil frame. In addition to this, the bracing must be adequate to take any compressive loading due to the collapsing stress set up by the catenary shapes of the turns, as well as from magnetodynamic effects. These loads are considered below in this order.

Dead Weight: The 1" diameter litz wire weighs 3/4 pounds per foot. Therefore, 2200 feet of wire in the coil will weigh approximately 1700 pounds. The dead weights of the insulator stacks can be estimated as 1200 pounds each, for a total of 1500 pounds per coil, including an allowance for the weight of small hardware items and top and bottom turns. Assuming each column of station posts has a footprint area of 3/4 sq. ft., the result is at most 2000 pounds per square foot of supporting surface or about 14 pounds per square inch. The compressive stress in the porcelain material itself is conservatively estimated as 12,000 pounds per square foot, if account is taken of the wall thickness of the (hollow) insulator.

Wind Loads: Wind load is calculated from the expression:

$$D = C_d \, A \, \rho \, U^2/2$$

where C_d is a drag coefficient, A is cross sectional areas, ρ is the density, and U is the velocity. A reference value for D for cylindrical conductors in air stream velocities less than 100 mph, is 6.4 kilograms per meter of exposed length for a wire 1.63 inches in diameter in 100 mile per hour wind. At 70 mph, this figure reduces to 1.33 pounds per foot of 1" diameter wire. Sixty wires 12 feet long each lying in each of two faces (the front and the rear) forming the projected area of the side of the coil yields 1920 pounds of wind shear force applied to the top of coil frame base members. This is 240 pounds per column which is well under the maximum allowable for any selection of candidate post insulator type when made of porcelain. The columns can be made of extruded polyvinyl tubing having dimensions typical of 6" diameter sewer pipe, in a concept that has been considered as a substitute for porcelain station posts should the latter not be available in the time frame required. In this concept careful attention will have to be paid to providing diagonal bracing in the lower portion of the coil frame supports to absorb the shear loads of the above magnitude.

Frame Crushing Loads: The conductor is hung between the supporting columns freely without other mounts and accordingly exerts a force equal to the tension in the catenary span at the supported ends. This is counterbalanced by an equal tension in the span coming up to the support point from the next adjacent coil face so that the column has no net tendency to sway sideways. However, since the two faces are not coplanar, but lie at an angle of 45°, there is a component of each of the tensions in a direction radially inward that tends to collapse the coil frame. This must be counterbalanced by providing bracing to the column in planes containing the coil frame centerline. The magnitude of the collapsing force on each column is calculated as follows using the diagrams and formulas given in Figure 11:

The total effective line density including dead weight and wind forces is $[(0.75)^2 + (1.33)^2]^{1/2} = 1.53$ pounds per foot. The horizontal component of tension in the catenary at the supported end is $T_h = (1.53)\,a$, where a is to be determined. If the sag at the center is d, the catenary formulas give

$$d = a[\cosh(\ell/2a) - 1]$$

Assume that the conductor can be put on with about 2% sag, and the span across the face of the coil between each adjacent pair of insulator columns is five feet. Then the sag d is 2% of 60 or 1.2" or 0.1 foot. One must then solve the transcendental equation

$$0.1 = a\,[\,\cosh\,(2.5/a) - 1]$$

By successive approximations a = 31 is close to a solution. Then T_h = (31)(1.53) = 47.5 pounds. From Figure 11, the inward crushing component of the force is 2 x (47.5) x Cos 67.5° = 36.5 pounds per turn and for 60 turns the total is 2200 pounds. If this is divided up into six planes of horizontal bracing, that is one set of braces per joint in the vertical column inside the coil frame, then the brace must withstand 365 pounds.

Some relief can be obtained by allowing the sag to be larger than 2%. Since for these small sags a square law relationship holds very well, raising the sag to 3% or nearly 2" in the five foot span reduces the compressive force per joint to about 180 pounds. By using a scheme that prevents the braces from buckling sideways such a compressive force can be readily absorbed either by a 5/8" diameter fiberglass rod or by a 2" diameter polyvinyl tube.

Magnetodynamic Loads: There are two forces due to the magnetic fields associated with the current in the coils that must be braced against in the coil frame structure. These are the force tending to collapse the coil endwise on itself and the force tending to expand each turn outwards. The last-named force is translated into a tendency for the coil to unwind itself since the bottom turn is fixed and the top turn is in a sense "free." The forces are calculated from formulas of Grover, pp 254 and following. This was done in February 1971 for helixes to be constructed in the OMEGA Navigation stations for coils similar to those under consideration here. Extrapolation to the present case can be done in proportion to current^2 and (number of turns)^2. When this is done it is found that the collapsing force is about 1 pound and the unwinding torque is about 26 pounds-feet (4.4 pounds acting tangentially at a radius of 6 feet). These forces are so small that they are inconsequential.

CAPACITOR

The only loads considered for the capacitor are dead weight and wind-induced shear loads. Electrostatic forces are entirely negligible. The latter are given by

$$F = \frac{\varepsilon_o}{2}\,(V/d)^2 \text{ (parallel plate capacitor)}$$

where MKS units apply. For 500 kV and separation distance of 4.6 meters, the result is 0.5 kgm,or about 1.8 ounces, per square meter. For the capacitor having sides of 80 feet, this would be about 70 pounds.* Certainly in the case of tubular conductors the actual total would be much less.

Dead Weight: There are roughly 80 x 9 feet of 0.125" wall thickness 8" diameter tubing which weighs 3.64 pounds per foot. Total dead weight of the grid structure is thus about 2700 pounds. The weight is divided among four columns weighing about 1200 pounds each so that on each footing there is about 2000pounds, comparable to the approximately 1500 pounds for the coil frame per column. Less than 25 pounds additional will be added by the electrostatic loads.

Wind Loads: Using the figure previously found for 1" diameter conductor of 1.33 pounds per foot for 70 mph wind, 8" conductor will experience 10.7 pounds per foot. Assuming the worst case exposure of winds from a direction 45°

*100 pounds peak

off the axis of the structure, 9 members will have their length $\times\sqrt{2}$ exposed, so that the total wind force will be 10.7 x 0.707 x 80 x 9 = 5500 pounds. This is 1370 pounds per column so that the types selected satisfy the structural criterion for shear loading with about a 50% safety factor. Applied 15 feet from the ground, the moment is 20,500 pounds-feet. A concrete block 8 feet square and one foot thick weighs 10,000 pounds and for an instantaneous axis of rotation about one edge exerts a moment of 40,000 pounds-feet. Therefore the anchorage provided in the present design are capable of resisting overturning of the columns with a safety factor of 2 for wind drag on the grid due to 70 mile per hour winds. The porcelain columns themselves add about 1900 pounds-feet to the load at each footing which represents approximately a 5% increase.

Tube Material Selection: The combined wind and dead weight load for the assumed tubing is $[3^2 + 10.7^2]^{1/2}$ = 11 pounds per linear foot. The beam formed by the tube suspended by its ends 40 feet apart must sustain a distributed load of 440 pounds without buckling. This is the situation for the five parallel conductors suspended from the cross-arms and for the two end members. The cross-arms must suspend a similar loading plus point loads at their ends equal to the dead weight of the conductors supported there at right angles. A structural analysis carried out by R. H. Chalmers of NELC gave 0.092 inch as the minimum wall thickness for 50 mph wind for the members suspended at their ends without point loads, and 0.17 inch for the cross-arms without trusses. This assumed aluminum without special heat treatment for increased tensile strength and assumes that the material is worked entirely within the elastic range. As a good compromise for the 70 mph criterion, 0.125 inch wall material was selected and the cross-arms are to be trussed with diagonal bracing made out of the same material. The detailed analysis is attached herewith as Appendix 2.

DOWNLEAD

The 4-inch diameter copper downlead was found to be fully capable of supporting 60 feet of its own dead weight applied axially but to be assured not to collapse due to sidewise wind loading, it must be guyed or otherwise supported in three locations. In the present design, these are the bottom end at the support insulator, the top end by a 52 inch cantilevered section at right angles to the vertical 60 foot run and one guyed point at the middle.

5. REFERENCES

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TABLE 1

CAPACITY VS APPARENT SERIES LOAD RESISTANCE

DRY VS WET

Surface	C pf	X ohms	R_c ohms	Q	$\|Z\|$ Ohms	$\|I\|$ Amp	P Watts	R ohms	L mhy
Dry	20	4×10^5	10^9	2.5×10^3	4×10^5	1.25	250	160	320
	63	12.7×10^4	"				"	16	
	200	4×10^3	"	2.5×10^4	4×10^4	12.5	"	1.6	320
	632	12.7×10^3	"				"	0.16	
	2,000	4×10^3	"	2.5×10^5	4×10^3	125	"	0.016	32
	6,320	12.7×10^2	"				"	0.0016	
	20,000	4×10^2	"	2.5×10^6	4×10^2	1250	"	0.00016	3.2
Wet	20	4×10^5	10^6	2.5	3.4×10^5	1.35	250×10^3	138×10^3	2950
	63	12.7×10^4	"				"	16×10^3	
	200	4×10^4	"	25	4×10^4	12.5	"	1600	320
	632	12.7×10^3	"				"	160	
	2,000	4×10^3	"	250	4×10^3	125	"	16	32
	6,320	12.7×10^2	"				"	1.6	
	20,000	4×10^2	"	2500	4×10^2	1250	"	0.16	3.2

f = 20 kHz

TABLE 2

TUNED CIRCUIT PARAMETER PAIR TRADES VS FREQUENCY

	10.1 kHz					14.3 kHz					16.6 kHz				
C pf	X	I	R	Q	L	X	I	R	Q	L	X	I	R	Q	L
10,000	1580	316	1.0	1580	25.8	1120	447	0.5	2240	12.9	960	520	0.37	2620	9.20
5,000	3160	158	4.0	790	516	2240	223.5	2.0	1120	25.8	1920	260	1.47	1310	18.4
2,500	6326	79	16.0	395	103.2	4480	112	8.0	560	51.6	3840	130	5.88	652	36.8
1,250	12640	395	64.0	197	206.4	8960	56	32.0	280	103.2	7680	65	23.5	326	73.6
625	25280	19	256	98.5	412.8	17920	28	128	140	206.4	15360	32.5	94.1	163	147.2

	19.8 kHz					23.4 kHz					28.5 kHz				3.12
C	X	I	R	Q	L	X	I	R	Q	L	X	I	R	Q	L
10,000	805	620	0.25	3100	6.45	680	736	0.185	3680	4.13	559	893	0.125	4490	3.12
5,000	1610	310	104	1550	12.9	1360	368	0.74	1840	9.25	1118	446	0.50	2236	6.23
2,500	3220	155	4.16	715	25.8	2720	184	2.96	920	18.5	2236	223	2.00	1118	12.46
1,250	6440	78	16.6	387	51.6	5440	92	11.8	460	37.0	4472	112	8.0	558	25.9
625	12880	39	66.6	194	103.2	10880	46	47.4	230	74.0	8944	56	32.0	279	51.8

TABLE 3

SINGLE CONDUCTOR CORONA LIMITS

a m	E_c kv/mm	h m	V_c kV	C_1 pf/m	Length for 2000 pf m
0.1	1.10	1	325	18.5	109
0.1	"	2	408	15.0	133
0.1	"	3	450	13.5	149
0.1	"	5	505	12.2	164
0.1	"	7.5	560	11.2	178
0.2	1.03	1	470	24.1	83
0.2	"	1.5	560	20.6	97
0.1	1.10	1	800*	20.2	110
0.1	"	0.5	630*	26.5	90
0.1	"	0.37	530*	30.5	77
0.1	"	0.2	900†	44.5	45

* D = 2.41 ϵ_r = 1.1

† D = 6.0 ϵ_r = 1.1

M = 0.8

F = 0.9

K = 0.95

H = 0.6

D = 1 exc. where noted

ϵ_r = 1 exc. where noted

TABLE 4

RELATIVE ROUGH COSTS, MAJOR CAPACITOR COMPONENTS

	Material	Shipping	Install.	Total
6" Tubing (per 100')	420	250	50	720
8" Tubing (per 100')	850	400	50	1300
Corona/Grading Rings (each)	750	250	50	1050
Station Posts (each)	800	200	250	1250
Welds (each)	---	---	20	20

TABLE 5

TUNING COIL VS AIR CAPACITOR SELECTION

L Range mhy	C pf net	C_o pf No insulator	C_{tor} pf with insulator	Frequency Tuning Range kHz
with fixed Helix[c] 18.9 - 21.0		$C_{net} + C_{trunk} + C_{do} = C_o$	$C_o + C_{con} + C_{insul} = C_t$	
	1040	1040 + 80 + 230 = 1350		31.5 - 29.9
			1350 + 80 + 140 = 1570	29.3 - 27.8
	1140	1450		30.4 - 28.8
			1670	28.4 - 26.5
	*1240	1550		*29.4 - 27.9
			1770	27.5 - 26.1
	*1340	1650		*28.5 - 27.0
			1870	26.9 - 25.4
	1290	1600		**29.1 - 27.5
			1820	27.3 - 25.8
No fixed Helix[c] 17.2 - 19.3	1040	1350		33.1 - 31.3
			1570	30.8 - 29.1
	1140	1450		31.9 - 30.2
			1670	*29.8 - 28.2
	1240	1550		30.8 - 29.2
			1770	*28.9 - 27.3
	1340	1650		*29.9 - 28.
			1870	28.3 - 26.0
	1290	1600		30.5 - 28.9
			1820	**28.8 - 27.0
[c]Varicmeter goes from 0.4 to 2.5 mhy helix is1.7 mhy. Coupling vario has been neglected.			1320 pf net	Can tune <u>without</u> helix with and without lead; can tune <u>with</u> helix, no load only

TABLE 6

Capacity Per Unit Length of Groups of n Parallel Conductors, $1 \le n \le 6$

All logs to base e

$$\epsilon_0 = \frac{1}{36\pi} \times 10^{-9} \text{ farads/m}$$

$$r = 2h/s$$

n = 1

$$C_{1,1} = \frac{2\pi\epsilon_0}{\log \frac{2h}{a}}$$

n = 2

$$C_{1,2} = 2\pi\epsilon_0 \left\{ \frac{2}{\left[\log \frac{2h}{a} (1 + r^2)^{1/2}\right]} \right\}$$

n = 3

$$C_{1,3} = 2\pi\epsilon \left\{ \frac{2}{\log \left[\frac{2h}{a} (1 + r^2)^{1/2} (1 + r^2/4)^{1/2}\right]} + \frac{1}{\log \left[\frac{2h}{a} (1 + r^2)\right]} \right\}$$

n = 4

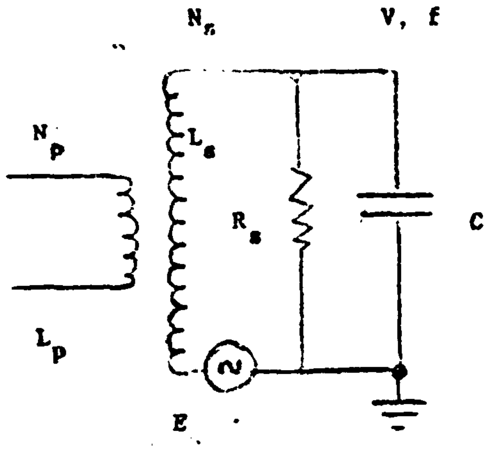
$$C_{1,4} = 2\pi\epsilon_0 \left\{ \frac{2}{\log \left[\frac{2h}{a} (1 + r^2)^{1/2} (1 + r^2/4)^{1/2} (1 + r^2/9)^{1/2}\right]} + \frac{2}{\log \left[\frac{2h}{a} (1 + r^2) (1 + r^2/4)^{1/2}\right]} \right\}$$

n = 5

$$C_{1,5} = 2\pi\epsilon_0 \left\{ \frac{2}{\log \left[\frac{2h}{a} (1 + r^2)^{1/2} (1 + r^2/4)^{1/2} (1 + r^2/9)^{1/2} (1 + r^2/16)^{1/2}\right]} + \frac{2}{\log \left[\frac{2h}{a} (1 + r^2) (1 + r^2/4)^{1/2} (1 + r^2/9)^{1/2}\right]} + \frac{1}{\left[\log \frac{2h}{a} (1 + r^2) (1 + r^2/4)\right]} \right\}$$

n = 6

$$C_{1,6} = 2\pi\epsilon_0 \left\{ \frac{2}{\log \left[\frac{2h}{a} (1 + r^2)^{1/2} (1 + r^2/4)^{1/2} (1 + r^2/9)^{1/2} (1 + r^2/16)^{1/2} (1 + r^2/25)^{1/2}\right]} + \frac{2}{\log \left[\frac{2h}{a} (1 + r^2) (1 + r^2/4) (1 + r^2/9)^{1/2} (1 + r^2/16)^{1/2}\right]} + \frac{2}{\log \left[\frac{2h}{a} (1 + r^2) (1 + r^2/4) (1 + r^2/9)^{1/2}\right]} \right\}$$



$$X = -i/\omega C$$

$$Q = R_s/X$$

$$P = V^2/R_s = I^2 R_e$$

$$I_r = V/R_s$$

$$I_c = V/X$$

$$|I| = (V/R_s)(1 + R_s^2/X^2)^{\frac{1}{2}}$$

$$= (V/R_s)(1 + Q^2)^{\frac{1}{2}} = (I_r^2 + I_c^2)^{\frac{1}{2}}$$

$$Z = V/(I_r + I_c)$$

$$|Z| = V/(I_r^2 + I_c^2)^{\frac{1}{2}}$$

$$= \left(\frac{1}{1/R_s^2 + 1/X^2}\right)^{\frac{1}{2}}$$

$$= R_s X/(R_s^2 + X^2)^{\frac{1}{2}}$$

$$= X/(1 + 1/Q^2)^{\frac{1}{2}} = R_s/(1 + Q^2)^{\frac{1}{2}}$$

$$R_e = P/|I|^2$$

$$= P/(I_r^2 + I_c^2)$$

$$N_s/N_p = n \quad (|Z|/Z_p)^{\frac{1}{2}}$$

For max V/E, secondary must be such that $L_s = |Z|/2\pi f$

$$= |Z|/\omega$$

$$= (1/\omega^2 C)(1 + 1/Q^2)^{-\frac{1}{2}}$$

$$= R_s/\omega(1 + Q^2)^{\frac{1}{2}}$$

FIGURE 1: TEST CIRCUIT ANALYSIS

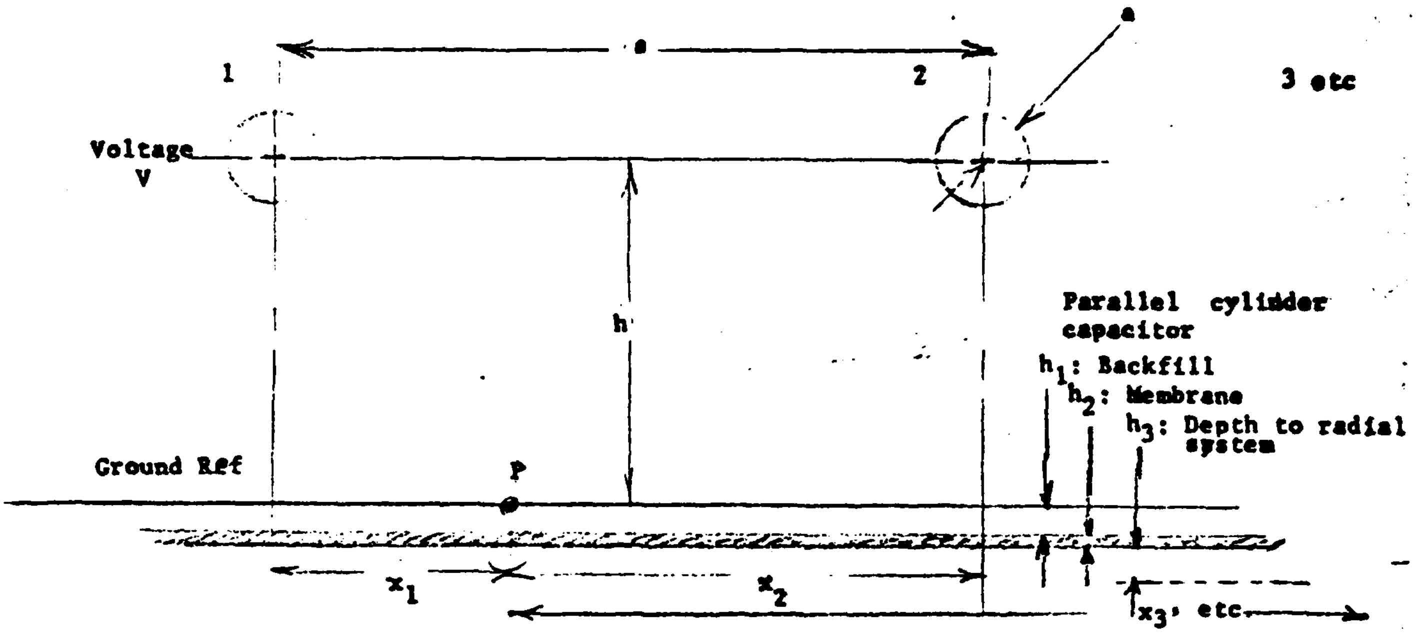
R_s is the shunt resistance that appears accross C during insulator tests.

E is the effective series voltage induced in the secondary circuit

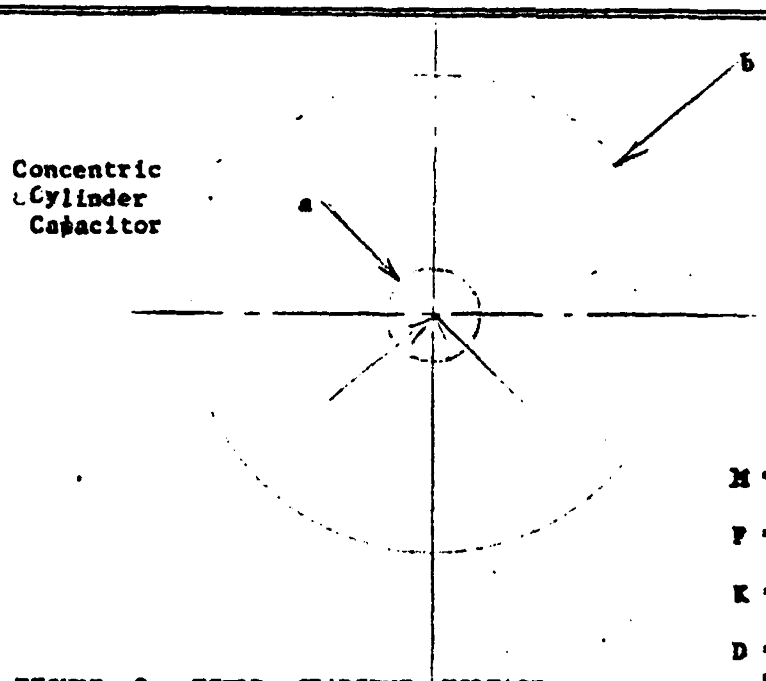
V is the voltage that appears across the secondary indf uctor at frequency f

R is the effective series reisistance referred to E in virute of power loss P at series current I

Note: Expression for V_c given below applies equally well for cylindrical conductor over plane, with quantities defined as indicated



$$|E_{y,P}| = \left[2V/(h \log_e 2h/a)\right]\left[(1 + x_1^2/h^2)^{-1} + (1+ x_2^2/h^2)^{-1} + \text{(etc., for all conductors)}\right]$$



$b = 2h$ $\quad \epsilon_0 = 10^{-9}/36\pi$ fd/meter

$C_1 = 2\pi\epsilon_0/\log_e(2h/a)$ fd/m

$$E_c = 2.35 \times 10^6 \times M \times F \times K \times D \times H \times \left[1 + \frac{0.032}{\sqrt{Ka}}\right]$$

$V_c = a\,E_c \log(2h/a)$ Volts

M = surface roughness factor = 0.8

F = frequency factor = 0.9

K = atmospheric density factor = 0.95

D = relative dielectric strength = 1 for air, 2.41 for SF_6 at 0# gage, 6 for SF_6 at 15#

H = rel Humidity factor, 0.6

E_c = limiting gradient for corona-free condition

FIGURE 2: FIELD, GRADIENT, VOLTAGE EXPRESSIONS FOR CAPACITY STRUCTURES

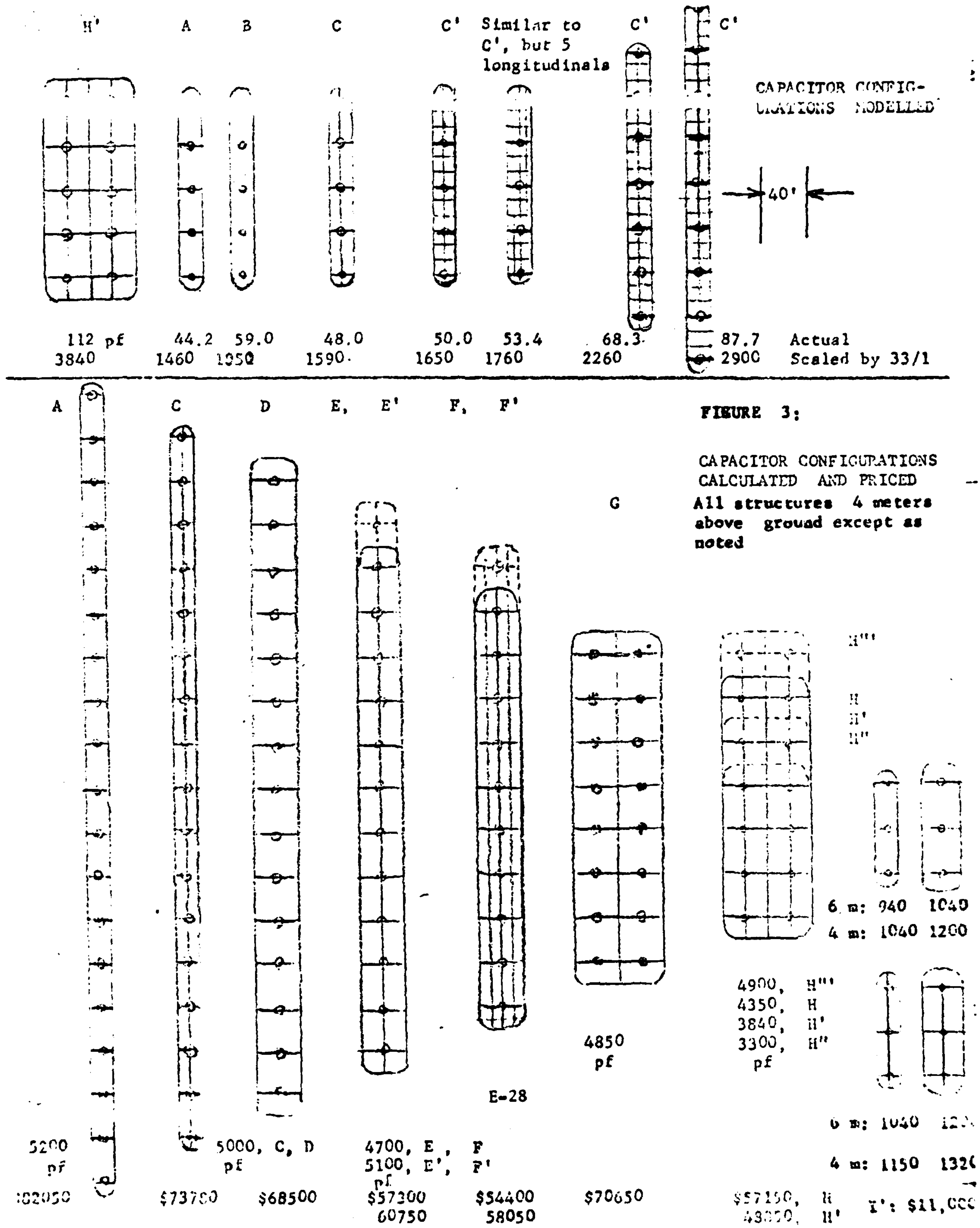
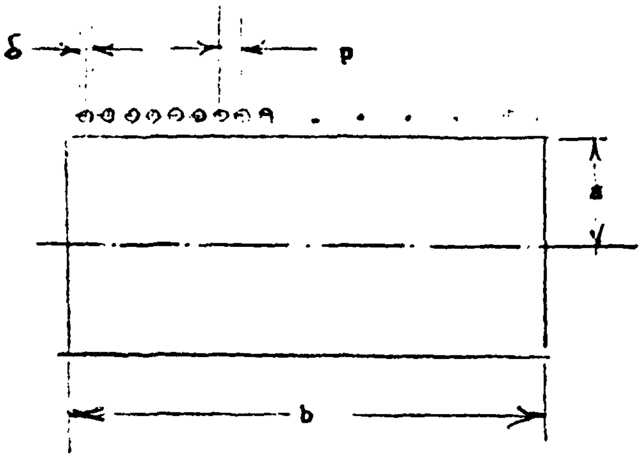


FIGURE 3:

CAPACITOR CONFIGURATIONS CALCULATED AND PRICED

All structures 4 meters above ground except as noted



Single layer solenoid

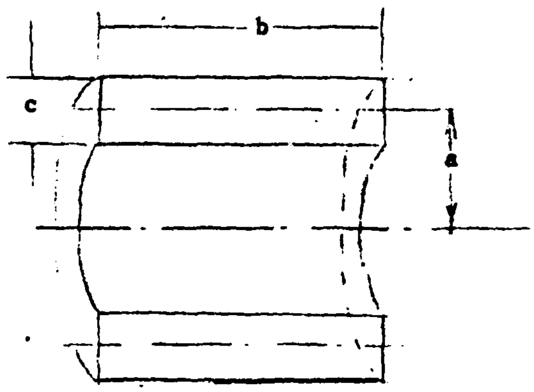
$L = 0.002\pi^2 a(2a/b)N^2K - \Delta L$ uhy

$\Delta L = 0.004\pi a(G + H)\, N$

b = length, cm
a = radius, cm
p = center-to-center wire spacing
δ = wire diameter

K = Nagaaka const = K(b/2a) or K(2a/b), Table 36, 37 Grover
G = G(δ/p), Table 38
H = H(N), N = no of turns, Table 39

ΔL usually << L



Multilayer Coil

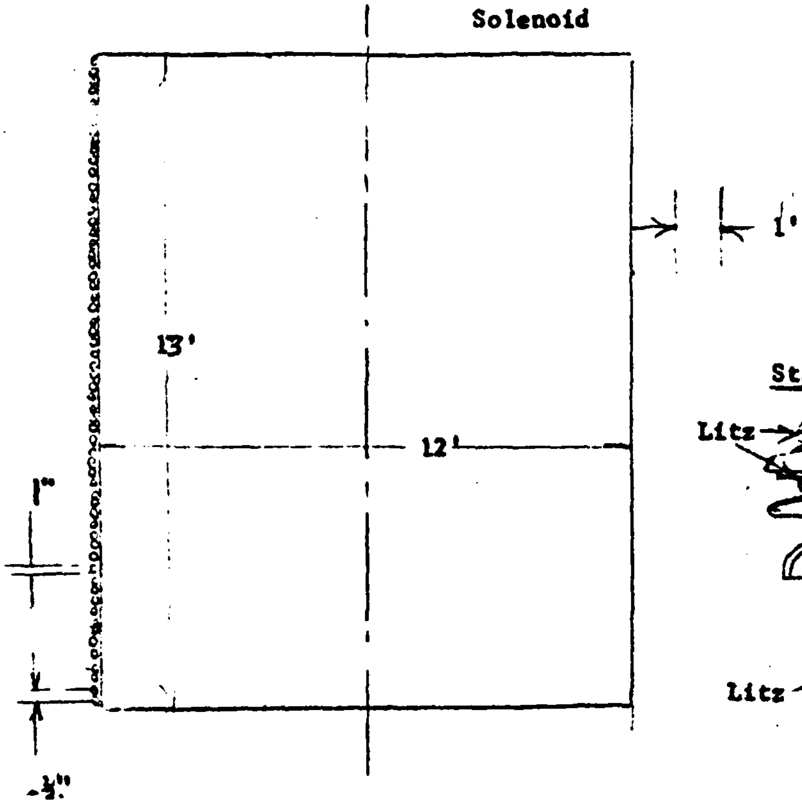
$L = 0.019739\ (2a/b)\ N^2\ K'$ uhy

K' = K - k, K is as above

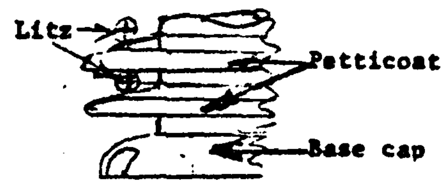
k = k(c/2a and c/b), Table 22, 23

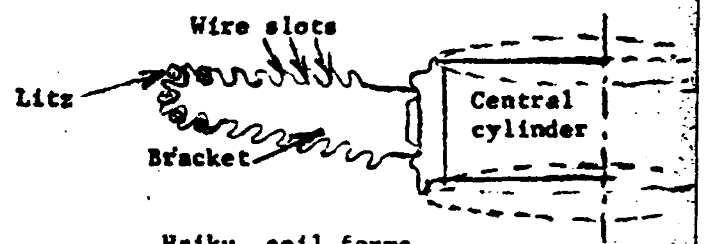
FIGURE 4: BASIS FOR COIL CALCULATION

FIGURE 5: PRINCIPAL DIMENSIONS OF COILS TO BE USED AT LLL: SOLENOID WILL ACTUALLY BE BUILT, PI WOUND COIL IS HAIKU FRAME CONSIDERED FOR POSSIBLE USE.



Station post used as coil form





Haiku coil forms

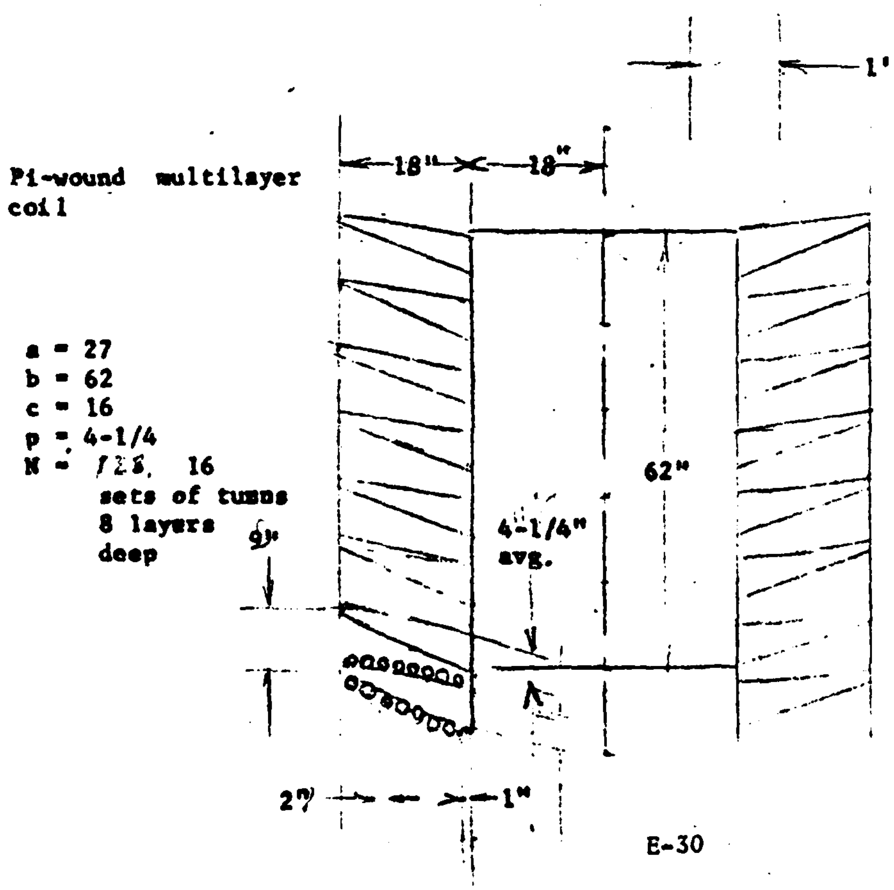


FIGURE 6: POSSIBLE COIL FORM LAYOUTS

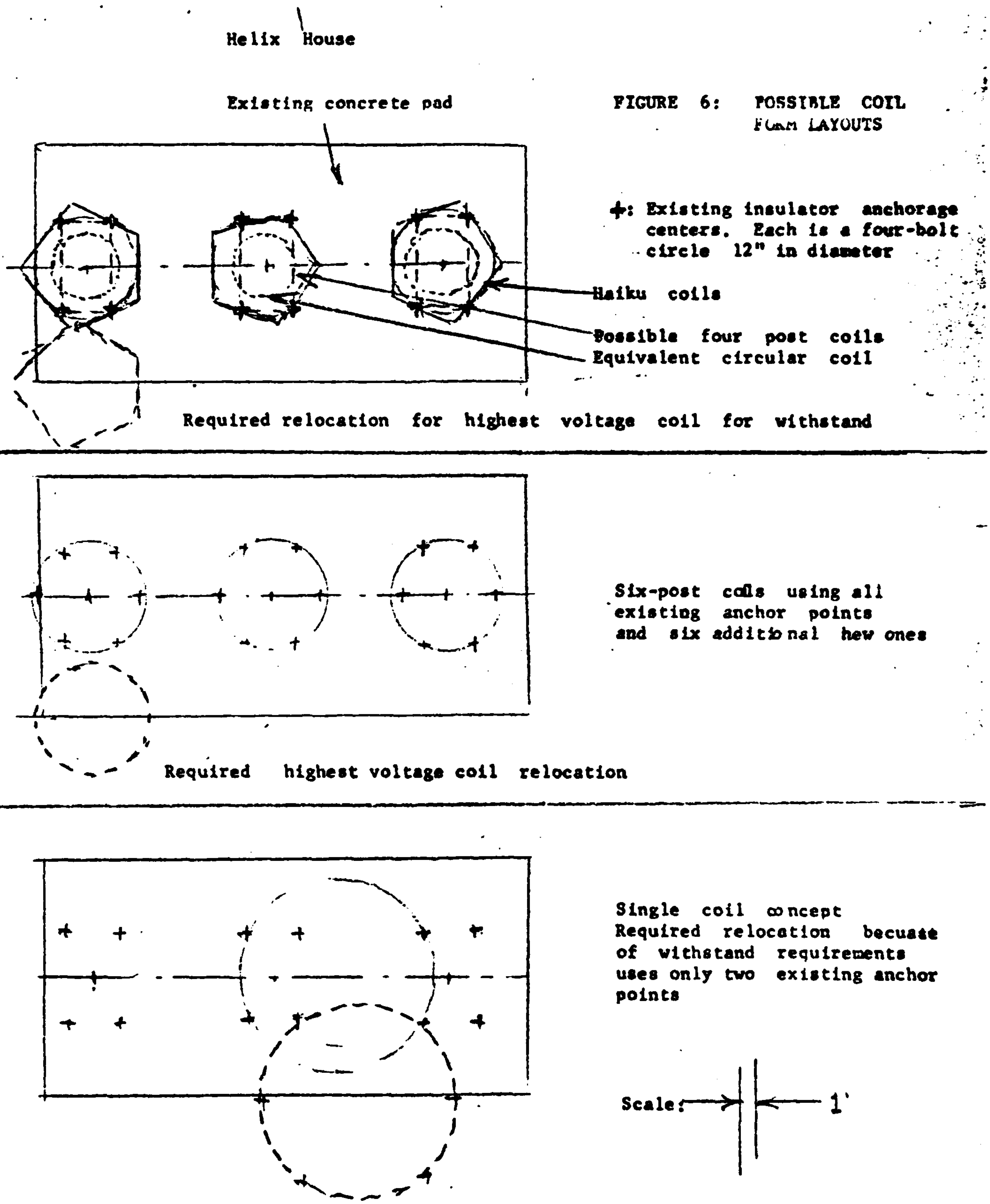
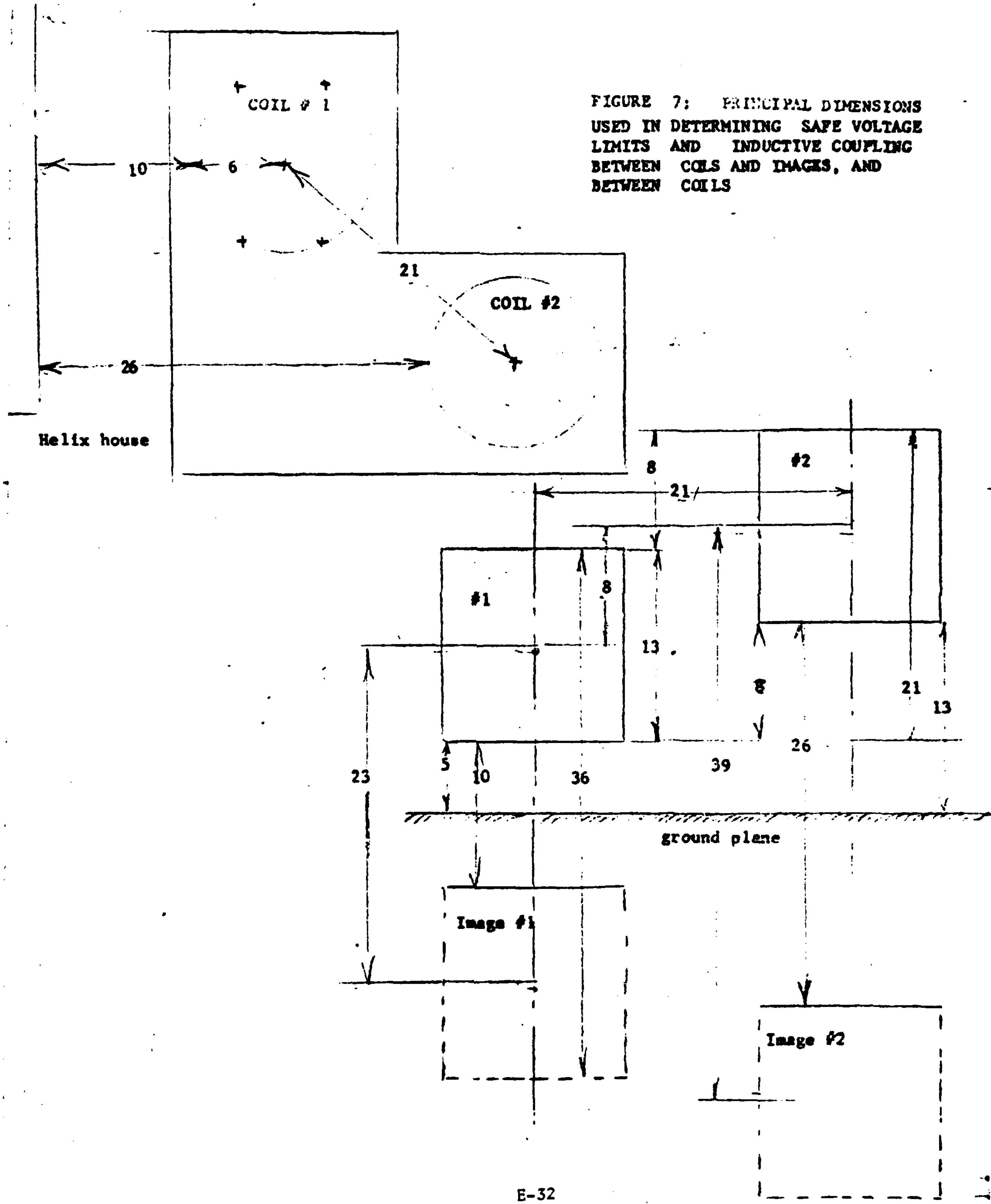
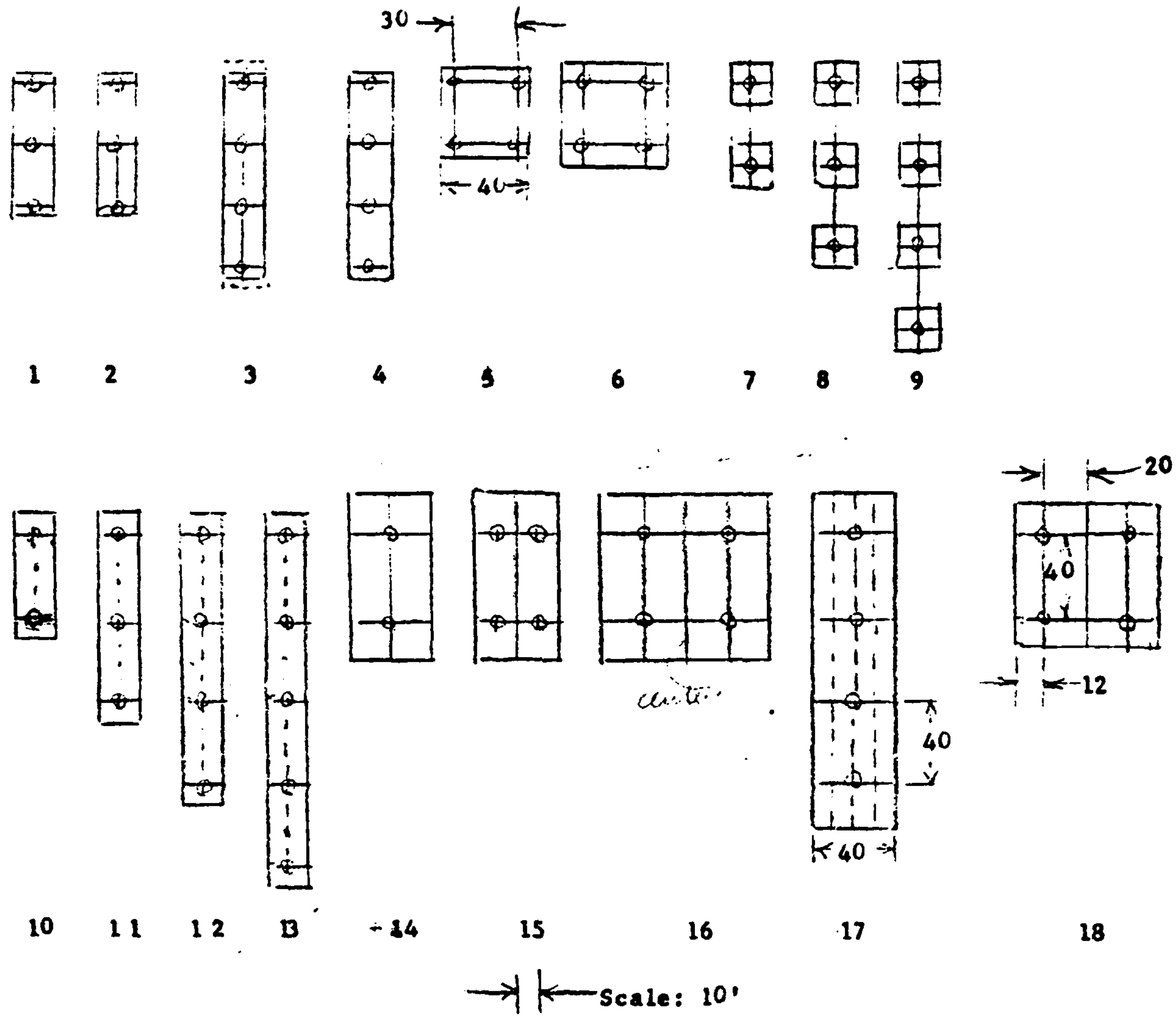


FIGURE 7: PRINCIPAL DIMENSIONS USED IN DETERMINING SAFE VOLTAGE LIMITS AND INDUCTIVE COUPLING BETWEEN COILS AND IMAGES, AND BETWEEN COILS





1: 700
2: 780
3: 915 (975 with extended ends)
4: 890
5: 720
6: 1070
7: 520
8: 800
9: 1100

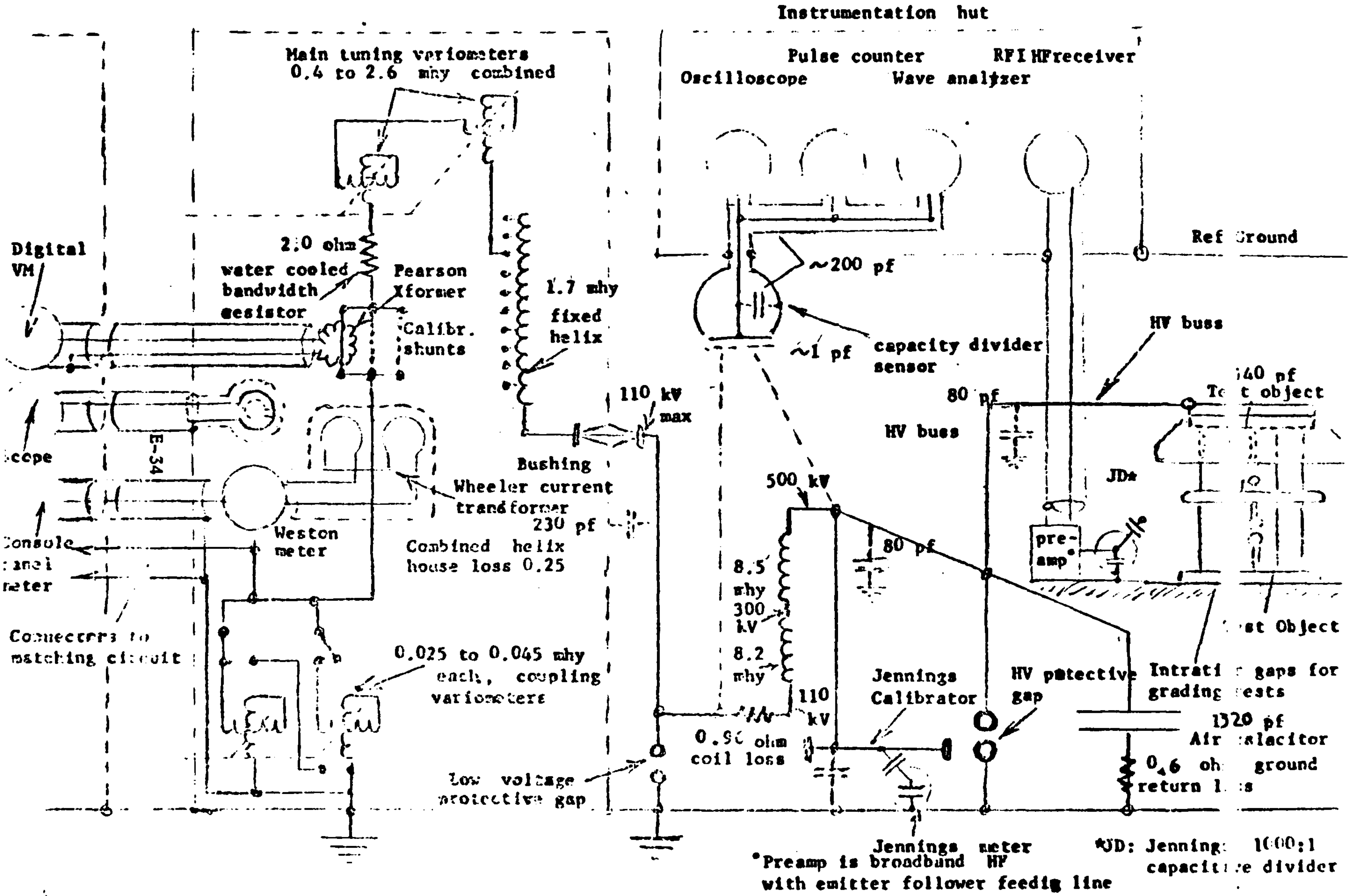
10: 550 (610 with center conductor)
11: 860 950 " " "
12: 1150 1300 " " "
13: 1400 1600 " " "
14: 1040
15: 1050
16: 1800
17: 1630; 1900; (2330 with five)
18: 1400

17 on 30' module: 1270, 1500, 1800

FIGURE 8 : PLAN VIEW SKETCHES OF POSSIBLE CAPACITOR STRUCTURES AND CAPACITY REALIZED. 4 meter height, 8" dia bus

All capacity values in picofarads

FIGURE 9: PRINCIPAL RF COMPONENTS IN TEST CIRCUIT AND INSTRUMENTATION



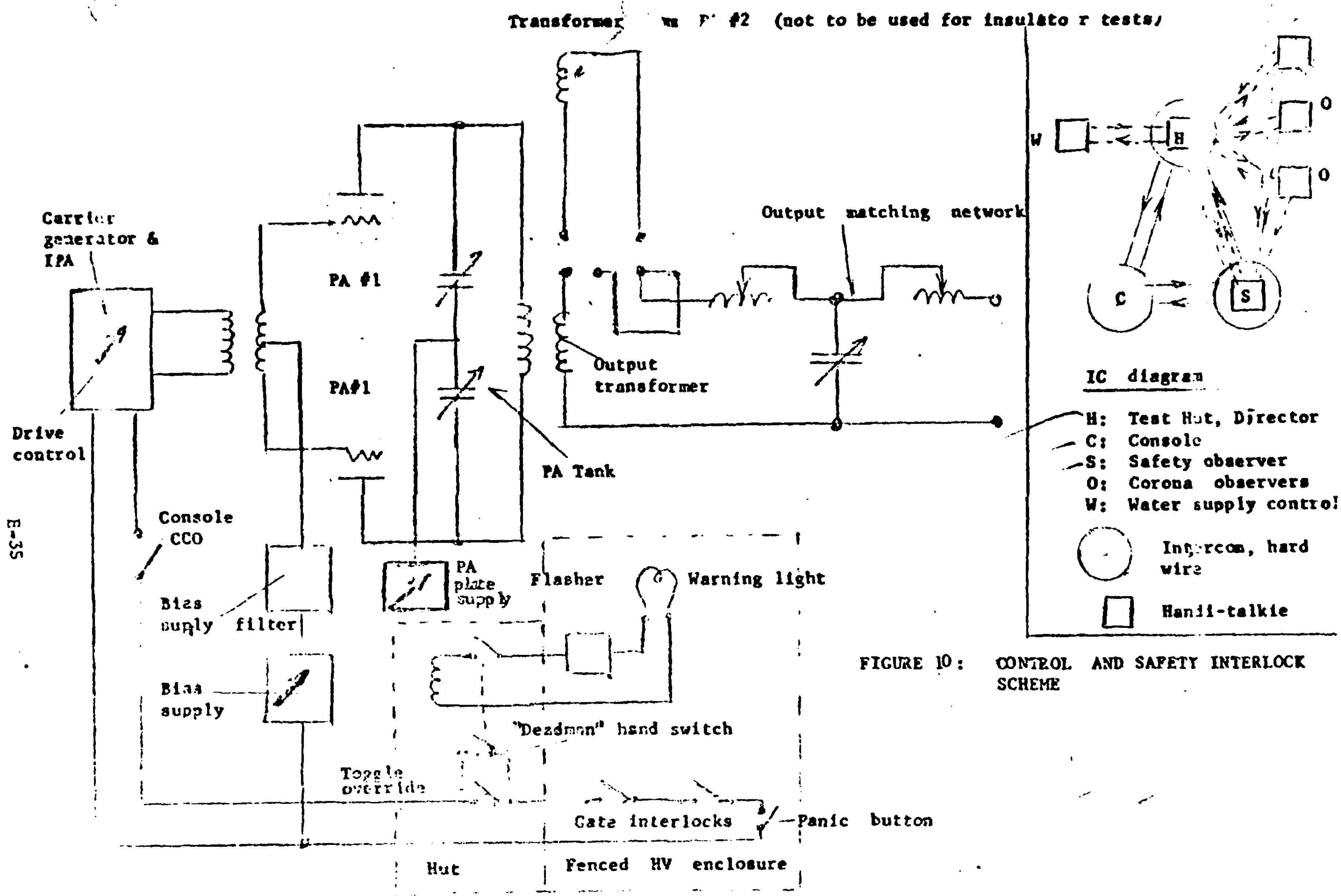


FIGURE 10: CONTROL AND SAFETY INTERLOCK SCHEME

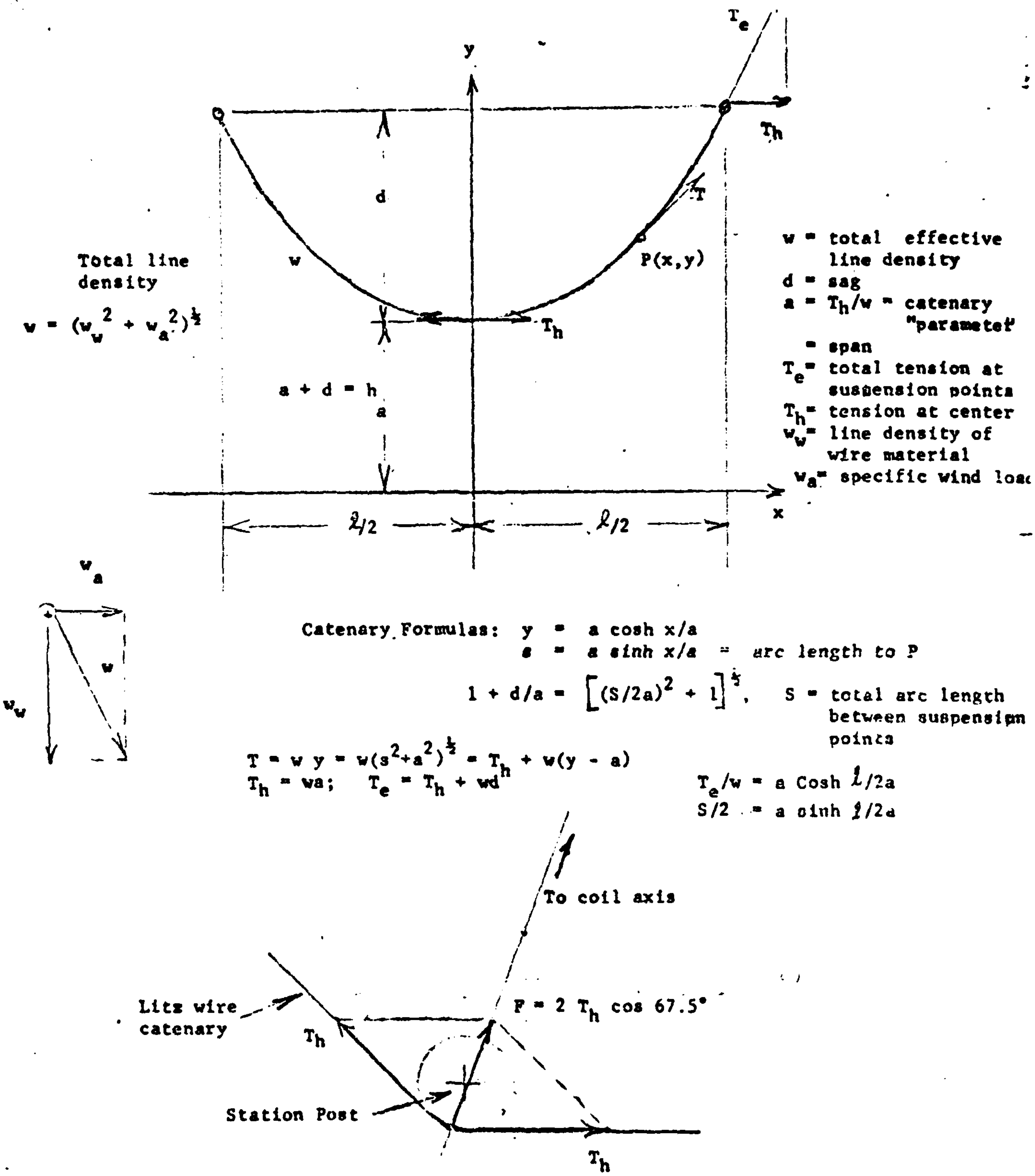


FIGURE 11: CATENARY RELATIONSHIPS AND THE CALCULATION OF COIL FRAME COLLAPSING FORCE

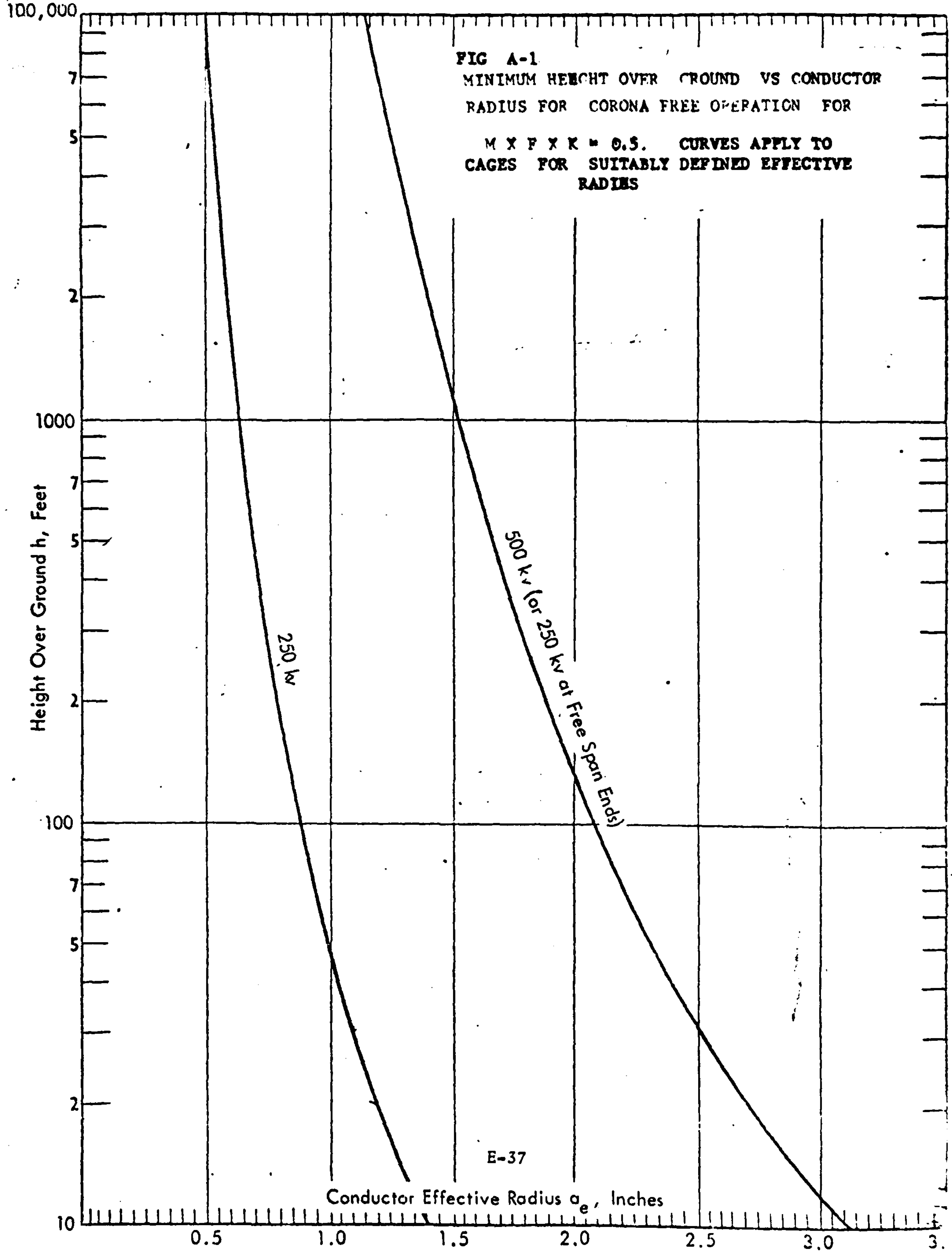


FIG A-1
MINIMUM HEIGHT OVER GROUND VS CONDUCTOR RADIUS FOR CORONA FREE OPERATION FOR
M X F X K = 0.5. CURVES APPLY TO CAGES FOR SUITABLY DEFINED EFFECTIVE RADIUS
100,000
7
5
2
1000
7
5
2
100
7
5
2
10
Height Over Ground h, Feet
250 kv
500 kv (or 250 kv at Free Span Ends)
0.5
1.0
1.5
2.0
2.5
3.0
Conductor Effective Radius a_e, Inches

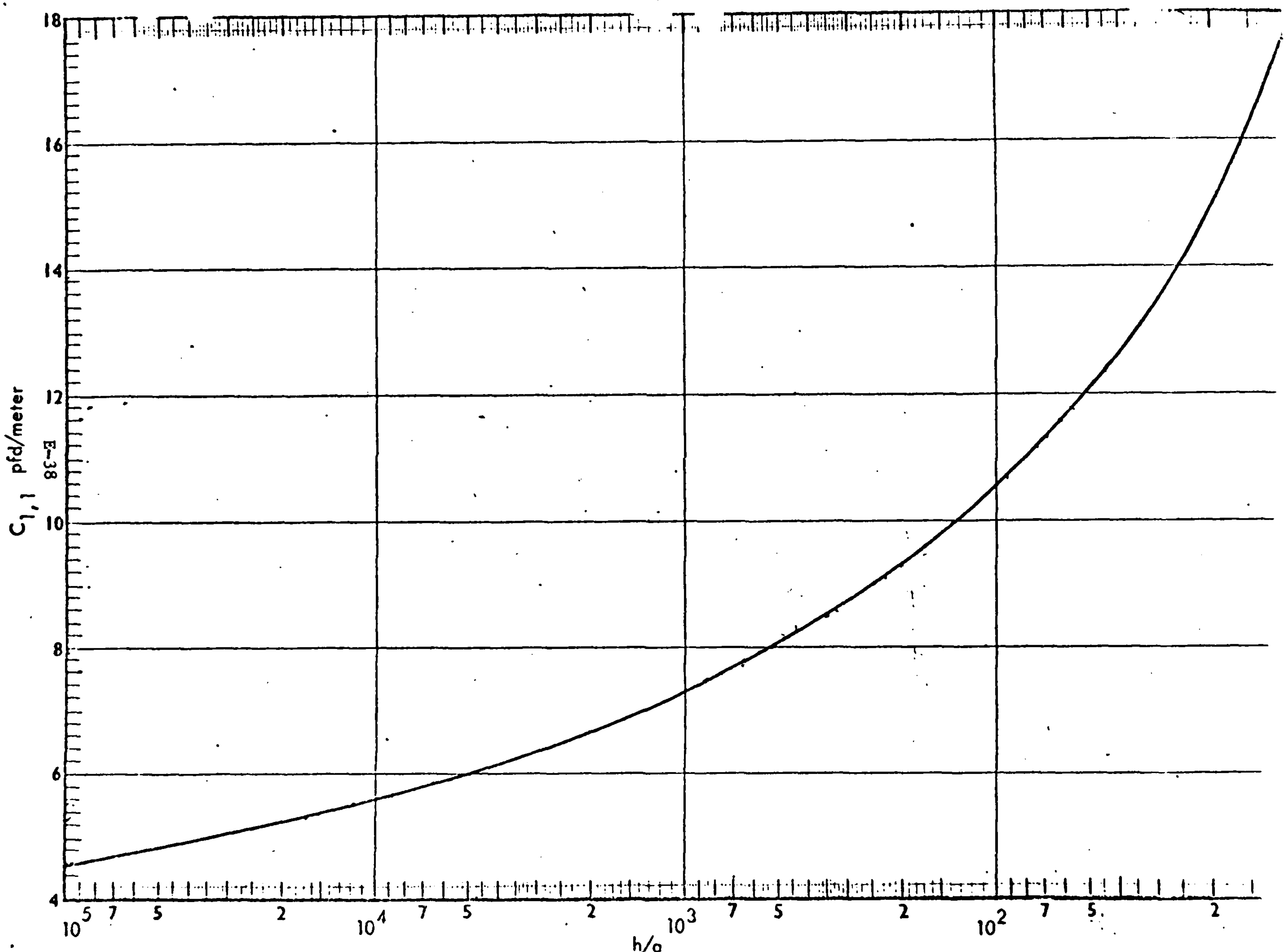


Figure A-2 Per Unit Length Capacity for Single Conductor

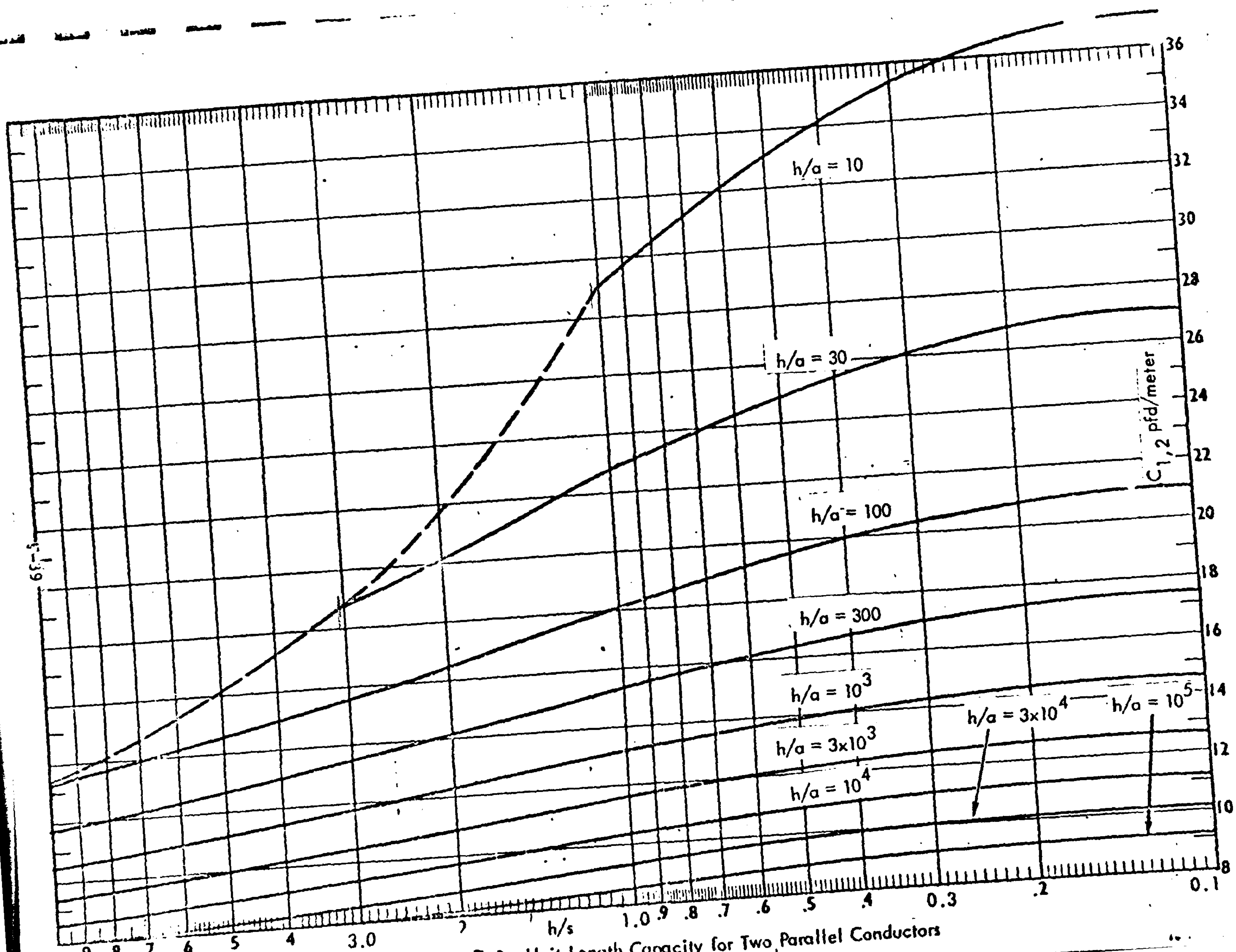


Figure A-3 Per Unit Length Capacity for Two Parallel Conductors

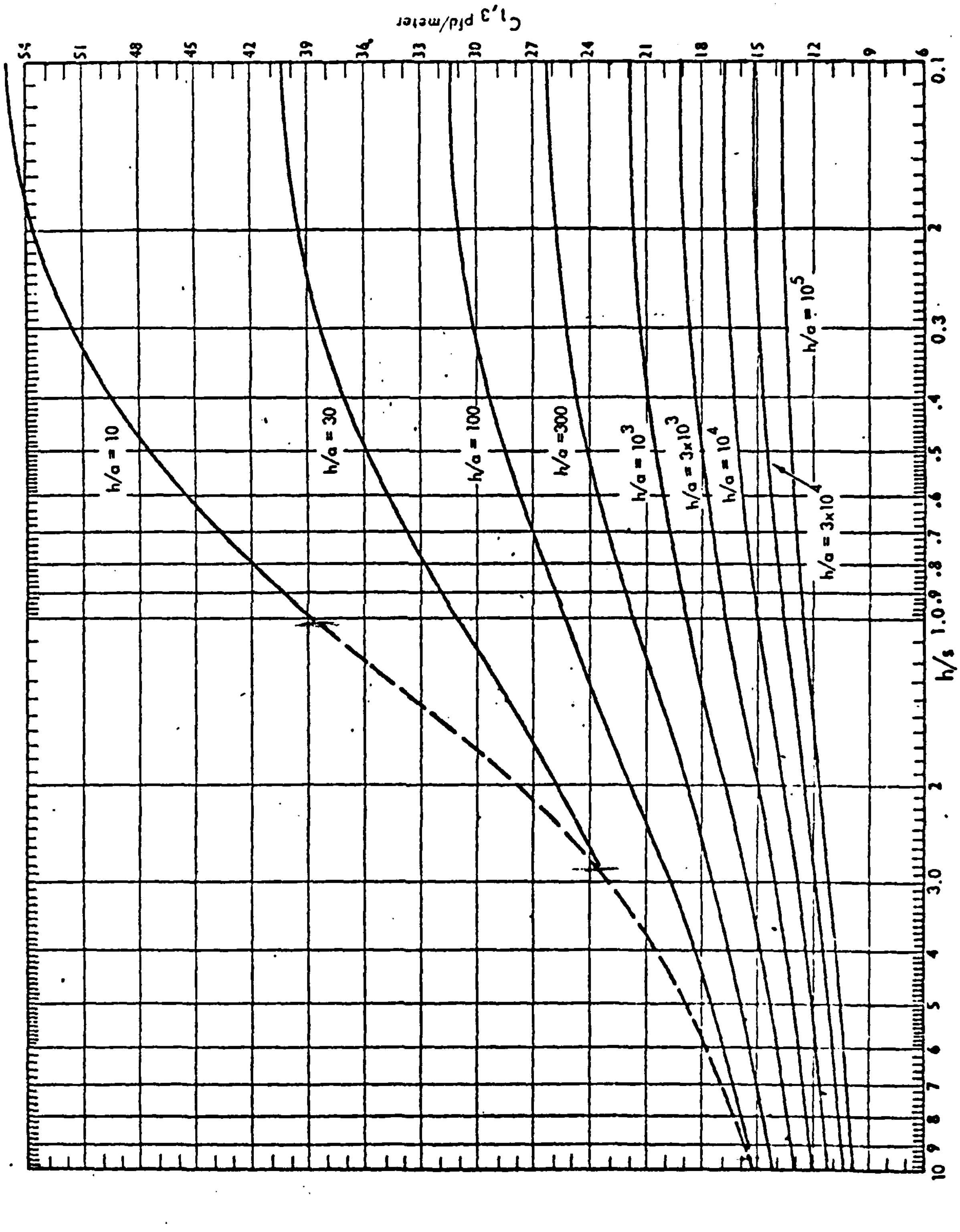


Figure A-4 Per Unit Length Capacity for Three Parallel Conductors

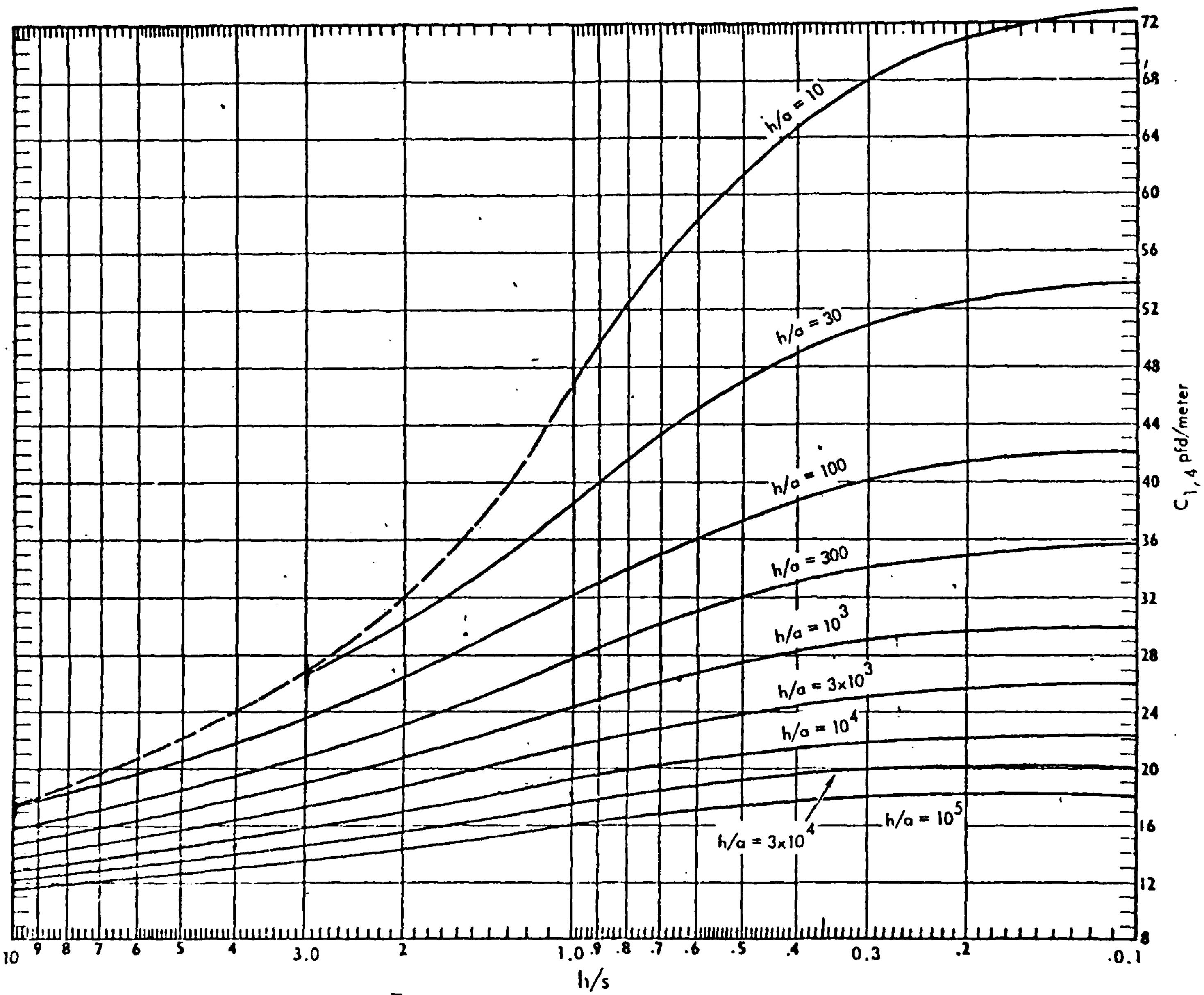


Figure A-5 Per Unit Length Capacity for Four Parallel Conductors

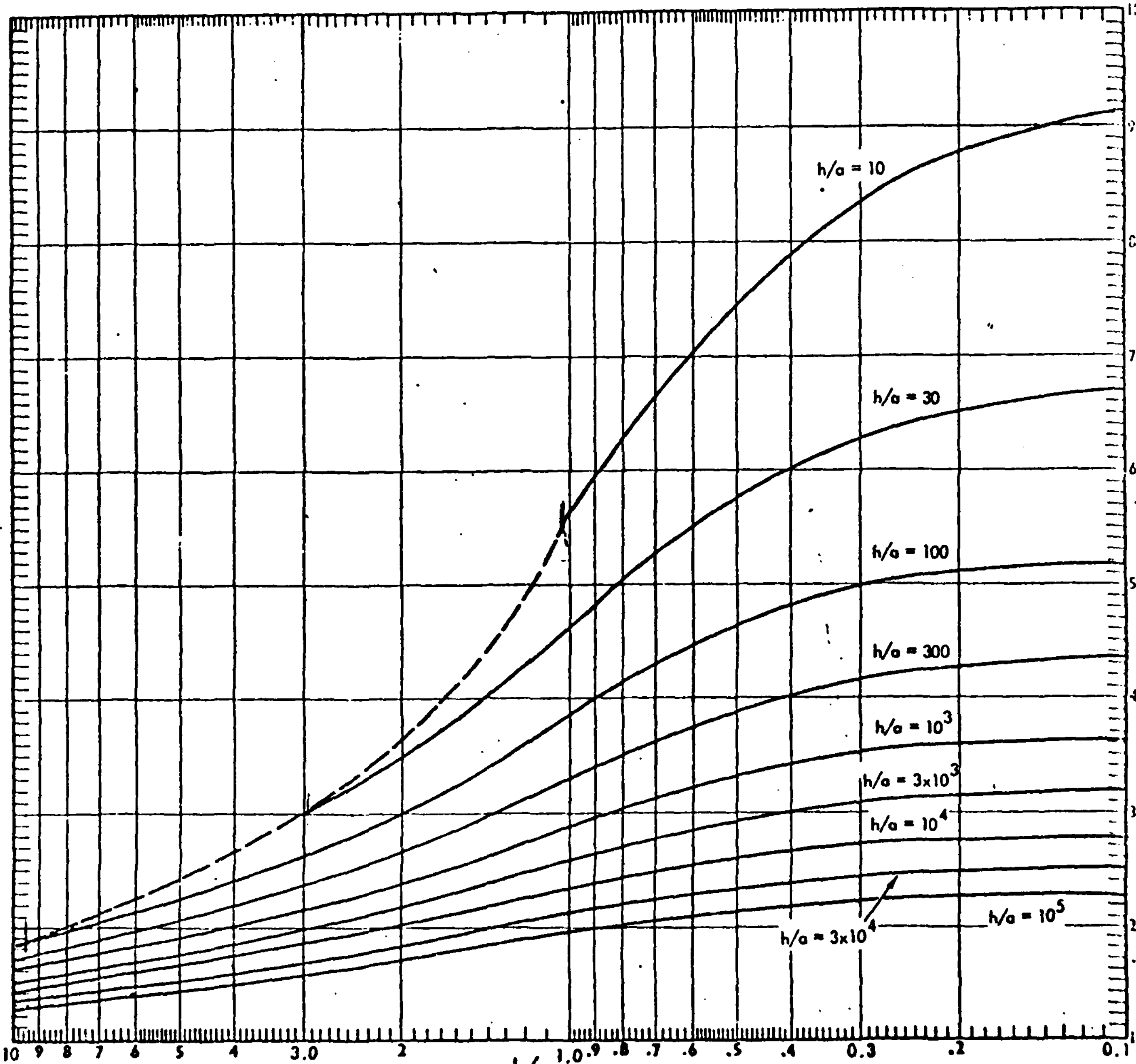


Figure A-6 Per Unit Length Capacity for Five Parallel Conductors

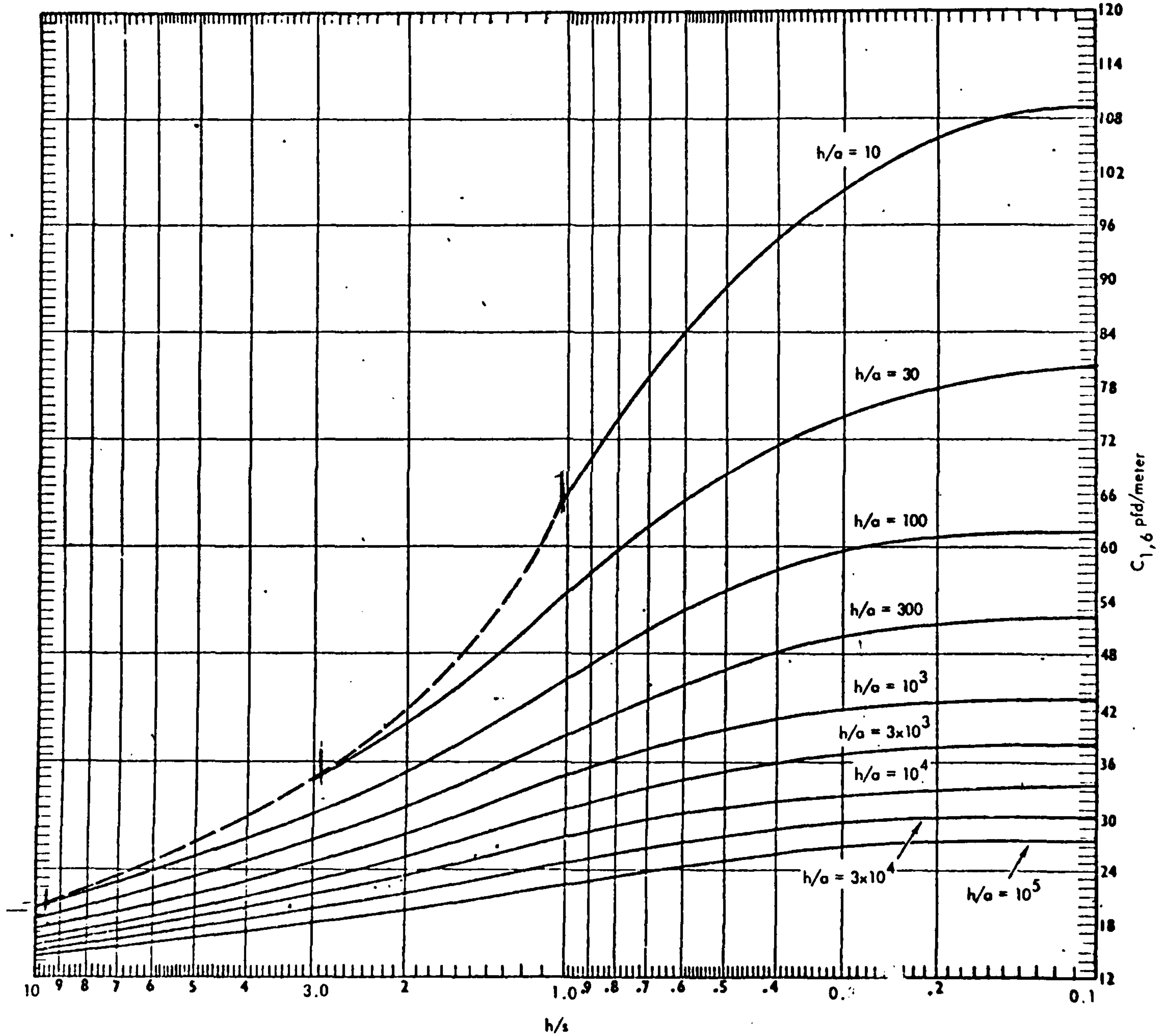


Figure A-7 Per Unit Length Capacity for Six Parallel Conductors

Serial No. ____41
ELEX-I-157
16 July 1973

NAVAL ELECTRONIC SYSTEMS COMMAND
CONTRACT SPECIFICATION

INSULATOR ASSEMBLY, ELECTRICAL, VLF ANTENNA BASE

This specification is for use only with Naval Electronic Systems Command contracts resulting from Procurement Request Number 311412 and will be furnished only to activities directly concerned with such contracts.

1. SCOPE

1.1 This specification covers the design, fabrication, and test of very low frequency (vlf) antenna tower base support insulator assemblies for installation at the base of vlf transmitting antenna towers at Naval radio transmitting facilities at shore locations.

2. APPLICABLE DOCUMENTS

2.1 The following documents of the issue in effect on date of invitation for bids or request for proposal, form a part of the specification to the extent specified herein:

SPECIFICATION

FEDERAL

TT-E-489	Enamel, alkyd gloss (for exterior and interior surfaces).
TT-P-00641	Primer coating; zinc dust-zinc oxide (for galvanized surfaces).

MILITARY

MIL-I-10	Insulating material, electrical ceramic, Class L.

FSC 5970

3.4.13 Interchangeability requirements. All parts of each base insulator assembly shall possess both mechanical and electrical compatibility to permit their installation as interchangeable parts. Interchangeability shall be in accordance with MIL-STD-454, requirement 7.

3.5 Service requirements. The vlf antenna tower base support insulator assembly shall be designed for a minimum operational life of not less than 25 years without loss of mechanical and electrical integrity. The design, choice of materials, parts selection, fabrication and assembling methods, surface protection, and other factors which determine durability and performance reliability shall be consistent with these requirements.

3.6 Maintainability. Routine inspection and minor adjustments for elements of the base insulator assembly other than the ceramic bodies of the insulator units shall not be required at intervals of less than 12 months and shall not require an interruption of service of more than 5 hours. Parts shall be mounted so they can be removed and replaced without interference from damage to, or removal of other parts. Insofar as practicable, parts most likely to fail or need repair shall have the easiest access.

3.6.1 Removal or replacement of rainshields, corona rings, and grading rings or shields shall be possible in a five hour period without damage or requiring jacking of the antenna tower.

3.6.2 Disassembly. The base insulator assembly shall be capable of being disassembled into its component parts without cutting, chipping or burning of any materials involved.

3.7 Environmental conditions. The base insulator assembly shall meet the electrical requirements of 3.3 under the following environmental conditions.

3.7.1 Location. The base insulator assembly shall be designed to operate in an outdoor exposed location.

3.7.2 Dust. The base insulator assembly shall withstand the effects of wind blown sand and dust as encountered in coastal regions throughout the world without permanent degradation of physical or electrical characteristics when tested as specified in 4.4.24.

3.7.3 Atmospheric pressure. The base insulator assembly shall be designed to operate at all atmospheric pressures which will be encountered in coastal regions throughout the world at altitudes ranging from sea level to 100 feet above sea level and in a nonoperating condition shall withstand without damage atmospheric pressures equivalent to those encountered at altitudes ranging from sea level to 40,000 feet above sea level.

3.7.4 Wind. The base insulator assembly shall be designed to operate

beneath the vlf antenna tower (see 3.9.1) in winds ranging from 0 to 100 miles per hour.

3.7.5 Ambient temperature. The base insulator assembly shall be designed to operate in ambient temperatures ranging from -25°C to 50°C.

3.7.5.1 Rate of ambient temperature change. The base insulator assembly shall be designed to operate in changes of ambient temperature up to 25°C per hour.

3.7.6 Humidity. The base insulator assembly shall be designed to operate in relative humidities ranging from 0 to 95 percent, including conditions wherein condensation takes place on the base insulator assembly.

3.7.7 Rain. The base insulator assembly shall be designed to operate under rainy conditions from light mist up to 2 inches per hour with intermittent rainfall of up to 0.2 inches per minute. The direction of the rain under which the base insulator assembly shall operate will be variable from vertical to horizontal (driving rain).

3.7.8 Snow. The base insulator assembly shall be designed to operate under snow or sleet conditions up to 2 inches per hour.

3.7.9 Lightning. The base insulator assembly shall be designed to withstand the effects of a direct hit on the antenna tower of lightning strokes as encountered throughout coastal regions of the world and as defined in the high current stroke paragraph of MIL-A-9094.

3.8 Electrical design and performance requirements.

3.8.1 Shunt capacitance. The total shunt capacitance of the base insulator assembly as measured from the top plate to the lower plate shall not exceed 250 picofarads.

3.8.2 Grading. The design of the base insulator assembly shall provide electrical grading such that the voltage across any one insulator unit is:

(a) 50 percent ± 5 percent of the total base insulator assembly voltage for a two tier assembly.

(b) 33 percent ± 3 percent of the total base insulator assembly voltage for a three tier assembly.

3.8.3 Uniformity of field. The maximum variation of the electromagnetic field in the air region immediately adjacent to the surface of the ceramic body of the insulator unit at the ceramic body/metallic end cap interface shall not be greater than three times the minimum field near the porcelain surface elsewhere.

3.8.4 Corona damage prevention. The base insulator assembly shall be designed such that any corona present under wet conditions will not produce degradation of the properties of materials or parts (see 4.4.1 and 4.4.2).

3.8.4.1 Ceramic-metal joint requirements. Joints between ceramic parts and metal parts shall be made with homogeneous material, free of voids, shims and foreign matter. Joints shall not exhibit characteristics under maximum tower loads which will cause excessive localized electrical stresses resulting in corona. A sealing compound shall be used to prevent the entrance of moisture into the joint between ceramic and metal parts.

3.8.4.2 Shunts. Where it is necessary to place nonconductive material (except insulator units) between metal parts, a conductive shunt or shunts shall be placed across the interface so as to ensure that metal parts will be at the same electrical potential. The design of the conductive shunt shall preclude the formation of corona in the gap between the metals and in the vicinity of the shunt itself.

3.8.5 Protection system design. The protection system shall provide a positive means for preventing any damage to the insulator units of the base insulator assembly in the event of flashover caused by lightning, overvoltage from any other source, or environmental conditions as specified herein.

3.8.5.1 The protection system shall confine flashovers to areas no closer to any ceramic material than the minimum dry arc distance across the insulator unit.

3.8.5.2 Corona. The protection system shall produce no detectable corona for continuous base insulator assembly operation at a voltage level of 285 kV rms in a frequency range extending from 10 kHz through 30 kHz with additional voltages present at frequencies other than the vlf operating frequency which combine to a value that is not in excess of 7 kV peak under both dry and wet conditions.

3.8.5.3 Tier-to-tier protection. The design of the protection system shall provide for individual protection of each tier of insulator units in the base insulator assembly.

Note: Corrections to called-out Voltages per Addendum #3 7 May 1973

3.8.5.4 The protection system shall be designed to remain intact and functioning after a vlf current surge through the protection system of 10 minutes duration generated by a 1.0 megawatt transmitter operating in the frequency range from 10 kHz to 30 kHz.

3.8.5.5 Adjustment. The protection system shall be designed to be simply adjustable to flashover at voltages from 200 kV to 500 kV rms at 60 Hz and at vlf. The protection system shall be calibrated for flashover in this voltage range.

3.8.5.5.1 The contractor shall specify a single fixed setting of the protection system operation that will meet the requirements of this specification (see 6.3).

3.8.5.5.2 The fixed setting of the protection system shall not require a readjustment when subjected to the environmental and electrical surge specified herein.

3.8.5.5.3 If special tools are required to accomplish this adjustment, they shall be provided. Special tools are defined as those tools not listed in the Federal Supply Catalog (copies of this catalog may be consulted in the office of the Defense Contract Administration Service (DCAS)).

3.8.5.6 Insofar as practicable, mechanical connections of metal parts in the discharge current path shall be by welding or brazing. If it is necessary that a bolted or other similar type connection be used in the discharge current path, current shunts shall be welded or brazed across the connection.

3.8.5.6.1 Current shunts shall be as short and as direct as possible and of sufficient size and number to carry the discharge current anticipated.

3.8.5.6.2 Current shunts shall be installed so that vibration, expansion, contraction, and the relative movement incidental to normal service use will not break or loosen the connection to such an extent that the resistance will vary during the movement.

3.8.6 60 Hz electrical performance requirements. Each base insulator assembly shall be designed in accordance with the following 60 Hz electrical requirements.

3.8.6.1 The 60 Hz wet flashover voltage shall not be less than ~~540~~ 515 kV rms for the base insulator assembly without the included protection system when tested in accordance with ANSI C29.1, modified to include application of water spray down to a horizontal direction.

3.8.6.2 The 60 Hz dry flashover voltage for the base insulator assembly

without the included protection system when tested in accordance with ANSI C29.1 shall not be less than ~~640~~ 625 kV rms.

3.8.6.3 The dry impulse withstand voltage for the base insulator assembly without its included protection system when tested in accordance with ANSI C29.1 shall not be less than 800 kV peak.

3.8.6.4 The 60 Hz dry visual corona extinction voltage for the base insulator assembly when tested in accordance with ANSI C29.1 shall not be less than 350 kV rms.

3.8.6.5 The radio influence voltage for the base insulator assembly when tested at 60 Hz at 300 kV rms under dry conditions in accordance with ANSI C29.1 shall not be greater than 30 microvolts rms.

3.8.6.6 The base insulator assembly with the protection system at the final setting specified by the contractor (see 3.8.5.5.1) shall flashover in the protection system when tested at 60 Hz (see 4.4.12).

3.8.6.7 The 5 minute continuous wet withstand voltage at 60 Hz for the base insulator assembly with the protection system at the final setting specified by the contractor (see 3.8.5.5.1) shall not be less than 300 kV rms.

3.8.7 <u>Vlf electrical performance requirements</u>. The base insulator assembly shall withstand the effects of a vlf flashover across its ceramic surfaces for ~~10~~ one seconds without mechanical damage. Each base insulator assembly (without the included protection system, except as noted in 3.8.7.7) shall meet the following vlf electrical requirements.

3.8.7.1 Wet flashover voltage for the base insulator assembly shall not be less than ~~400~~ kV rms. 375

3.8.7.2 Dry flashover voltage for the base insulator assembly shall not be less than ~~475~~ kV rms. 450

3.8.7.3 Dry corona onset and extinction voltage at vlf shall not be less than 285 kV rms.

3.8.7.4 Localized corona under wet conditions on the base insulator assembly shall not result in a temperature rise of any part of the base insulator assembly that will exceed 30°C above the existing ambient temperature under continuous operation at ~~300~~ kV rms. 150 + ~~[illegible]~~

3.8.7.5 Maximum temperature rise of any part of the base insulator assembly shall not exceed 30°C above specified ambient temperature under continuous operation at ~~300~~ kV rms. 250

3.8.7.6 The 60 minute continuous wet withstand voltage for the base insulator assembly shall not be less than 300 kV rms.

3.8.7.7 The base insulator assembly with the protection system at the final setting specified by the contractor (see 3.8.5.5.1) shall flashover in the protection system when tested at vlf (see 4.4.22).

3.9 Mechanical design and performance requirements.

3.9.1 Mechanical loading. The base insulator assembly, adapter plate, and grillage shall be capable of resisting simultaneously the following maximum working load when installed under the tower.

Horizontal working load: 25,000 lbs.
Vertical working load: 3,300,000 lbs.

The horizontal working load shall be considered as being applied at the top of the adapter plate in any horizontal direction. The vertical working load shall be considered as being applied at the top adapter plate 3 inches (76.2 mm) off the vertical centerline of the base insulator assembly, and along the axis of the applied horizontal working load such that the combined effect of horizontal and eccentric loading is additive.

3.9.2 Safety factor. The base insulator assembly, or any of its components, shall have a safety factor of at least 2.0 times the maximum, combination horizontal and vertical eccentric loading without mechanical damage and at least 3.0 times the maximum combination horizontal and vertical eccentric loading without mechanical failure.

3.9.3 Construction and assembly.

3.9.3.1 Physical requirements. The base insulator shall meet the following physical requirements:

3.9.3.1.1 Height requirements. The total vertical height of the base insulator assembly, the adapter plate, and the grillage shall match the total available height shown on the appropriate Naval Facilities Engineering Command drawing Nos. 3004582 and 3005498.

3.9.3.1.2 Interface requirements. The adapter plate shall be compatible with the existing tower base rocker assembly. The grillage shall be compatible with the existing base plate. Both the rocker assembly and the base plate are shown on the appropriate Naval Facilities Engineering Command Drawing Nos 3004582 and 3005498.

3.9.3.1.3 Installation dimensional requirement. The base insulator assembly, the adapter plate, and the grillage shall be capable of being inserted under the tower through a vertical opening in the tower jacking frame. The size of the opening measured in the vertical plane is approximately 120 inches high by 96 inches wide. The tower jacking system will provide for lowering and raising the tower no more than 2 inches below or above the space available under the tower.

4.3.5 60 Hz electrical inspection. The 60 Hz electrical inspection shall be conducted in accordance with ANSI C29.1 except as otherwise specified herein. Each base insulator assembly shall be tested fully assembled, complete with adapter plate, and grillage except as otherwise specified herein. The insulator shall be located in the center of a clear area not less than 20 feet on a side. The insulator grillage shall be connected to a grounded conductive surface at least 20 feet on a side. The test voltage shall be applied through a suitable conductor to the approximate center of the adapter plate. The conductor configuration shall be such as to minimize the distortion of field in the test stand compared with that existing when the insulator is installed under a tower. The following tests shall be conducted:

TABLE IH

Examination or test	Requirement paragraph	Test method paragraph
60 Hz wet flashover voltage test	3.8.6.1	4.4.6
60 Hz dry flashover voltage test	3.8.6.2	4.4.7
Dry impulse withstand voltage test	3.8.6.3	4.4.8
Calibration test	3.8.5.5	4.4.9
60 Hz dry visual corona test	3.8.6.4	4.4.10
Radio influence voltage test	3.8.6.5	4.4.11
60 Hz flashover mode test	3.8.6.6	4.4.12
60 Hz wet withstand test	3.8.6.7	4.4.13

4.3.5.1 Upon completion of the inspection of 4.3.5, the following tests shall be conducted on the complete base insulator assembly:

TABLE IJ

Examination or test	Requirement paragraph	Test method paragraph
Surface examination	(see table IA)	4.4.1
Ultrasonic test	3.4.1.1	4.4.2

4.3.6 Vlf electrical inspection. The vlf electrical inspection shall be conducted in accordance with ANSI C29.1 except as otherwise specified herein. Each base insulator assembly shall be tested fully assembled, complete with adapter plate and grillage (if required). The base insulator assembly shall be located outdoors in the center of a clear area, not less than 20 feet on a side. The base plate or grillage shall be connected to a grounded conductive surface or wire grid at least 20 feet on a side. The test voltage shall be applied through a suitable conductor to the approximate center of the adapter plate.

4.3.6.1 The following tests shall be conducted. The shunt capacitance and grading test shall be conducted prior to conduction of the other tests listed. The calibration test shall be conducted prior to the tests which follow it in the table.

TABLE IX

Examination of test	Requirement paragraph	Test method paragraph
Shunt capacitance test	3.8.1	4.4.14
Electrical grading test	3.8.2	4.4.15
Vlf wet flashover voltage test	3.8.7.1	4.4.16
Vlf dry flashover voltage test	3.8.7.2	4.4.17
Vlf continuous wet withstand voltage test	3.3.1, 3.7, 3.8.7.6	4.4.18
Calibration test	3.8.5.5, 3.8.5.5.1	4.4.9
Vlf dry corona test	3.8.7.3, 3.8.3, 3.8.4 3.8.4.1, 3.8.4.2, 3.8.5.2	4.4.19
Vlf wet corona heat rise test	3.8.7.4, 3.8.3, 3.8.4 3.8.4.1, 3.8.4.2, 3.8.5.2	4.4.20
Vlf dry heat rise test	3.8.7.5	4.4.21

Vlf flashover mode test	3.3, 3.3.2, 3.3.2.2, 3.7, 3.8.7.7	4.4.22
Vlf interruption test	3.3.2, 3.3.2.2, 3.3.2.3, 3.3.2.3.1, 3.7	4.4.23

4.3.6.2 Upon completion of the tests of 4.3.6.1, the following tests shall be conducted on the base insulator assembly:

TABLE II

Examination or test	Requirement paragraph	Test method paragraph
Surface examination	(see TABLE IA) 3.3, 3.3.1, 3.3.1.2, 3.3.2, 3.7	4.4.1
Ultrasonic test	3.4.1.1, 3.3, 3.3.1, 3.3.1.2, 3.3.2, 3.7	4.4.2

4.3.7 Inspection of preparation for delivery. Sample packages and packs and the inspection of the preservation and packaging, packing and marking for shipment and storage shall be in accordance with the requirements of section 5.

4.4. Inspection procedures.

4.4.1 Surface examination. Surface examination shall be in accordance with MIL-E-16400 except as otherwise specified herein. The equipment shall be examined to verify compliance with this specification as to design and construction and to other inspections deemed necessary by the procuring activity to assure conformance with requirements not covered by the other tests of this specification. Ceramic surfaces shall be inspected by the ultraviolet-red dye method. Any evidence of defects in materials, cracking, mechanical damage, mechanical failure, or permanent deformation shall result in rejection.

4.4.2 Ultrasonic test. The contractor shall utilize ultrasonic test equipment (Branson model 50C, or equal) to test the ceramic bodies of the insulator units. A calibrated permanent record, such as by camera photograph or x-y plotter record, shall be obtained for every ultrasonic test measurement indicating a possible void or discontinuity in the ceramic body of each insulator unit. This record shall be calibrated in amplitude and width. The location of the measurement point on the insulator unit and the insulator unit serial number shall also be indicated on or attached to the record. The widest possible inspection of each insulator unit ceramic shall be accomplished. Any mechanical damage or evidences of internal discontinuities, cracks, defects, or voids shall result in rejection of the insulator unit or the base insulator assembly as appropriate.

4.4.3 Mechanical tests.

4.4.3.1 The surface examination of 4.4.1 shall be conducted on the insulator unit.

shall be capable of carrying 300 percent of the basic leg working load without failure. Failure of the average strength of the three insulators to meet the strength requirement of 350 percent of the basic leg working load, or failure of any one insulator to meet 300 percent of the basic leg working load shall constitute failure to meet the requirements of the specification.

4.4.5 Base insulator assembly proof load test. Each base insulator assembly, with the adapter plate and grillage, shall be tested with a total load of 200 percent of the basic leg working load times the number of legs in the assembly. The base insulator assembly proof load test is to be conducted as follows:

4.4.5.1 The surface examination of 4.4.1 shall be conducted on the base insulator assembly.

4.4.5.2 The base insulator assembly shall be slowly and smoothly loaded at 50 percent of the maximum vertical working load. The load shall then be smoothly decreased to zero.

4.4.5.3 The base insulator shall then be slowly and smoothly loaded in twenty equal incremental steps to the total proof load described above. The load shall then be smoothly and slowly decreased in twenty equal incremental steps to zero. During each step of the incremental loading and unloading, sufficient data shall be recorded to prepare a strain versus total load diagram for the base insulator assembly and for each insulator leg.

4.4.5.4 The surface examination of 4.4.1 shall be conducted on the base insulator assembly.

4.4.5.5 The ultrasonic test of 4.4.2 shall be conducted on each and every insulator unit of the base insulator assembly.

4.4.6 60 Hz wet flashover voltage tests.

4.4.6.1 Standard test. The 60 Hz standard wet flashover voltage test shall be conducted on the base insulator assembly for water spray application downward at an angle of 45 degrees from the vertical in accordance with ANSI C29.1 except as otherwise specified herein.

4.4.6.2 Horizontal spray test. The 60 Hz horizontal spray wet flashover voltage test shall be conducted on the base insulator assembly in accordance with the 60 Hz wet flashover voltage test of ANSI C29.1 with the exception that the application of the water spray shall be in a horizontal direction and except as otherwise specified herein.

4.4.7 60 Hz dry flashover voltage test. The 60 Hz dry flashover voltage test shall be conducted on the base insulator assembly in accordance with ANSI C29.1 except as otherwise specified herein.

4.4.8 Dry impulse withstand voltage test. The dry impulse withstand voltage test shall be conducted on the base insulator assembly under dry conditions in accordance with the impulse withstand voltage test of ANSI C29.1 except as otherwise specified herein.

4.4.9 Calibration test. The protection system shall be calibrated in accordance with test procedures described in ANSI C29.1. The following calibration measurements at 60 Hz or vlf as appropriate shall be conducted on the base insulator assembly including the protection system.

4.4.9.1 Under dry conditions the protection system shall be calibrated for flashover in the protection system in the voltage range from 200 kV rms to the dry flashover voltage of the base insulator assembly(operating without the included protection system)or 500 kV rms whichever is the lesser. The total number of settings or adjustments to determine calibration shall not be less than 10, and shall include flashovers in the protection system at the following nominal voltages: 200 kV, 250 kV, 300 kV, 350 kV, 400 kV, 450 kV, 500 kV.

4.4.9.2 Under wet spray conditions at the maximum rate as required by this specification and for spray in a horizontal direction, the protection system shall be calibrated for flashover in the protection system in the voltage range from 200 kV rms to the wet flashover voltage of the base insulator assembly (operating without the included protection system) for the same spray conditions or 500 kV rms whichever is the lesser. The total number of settings or adjustments to determine calibration shall not be less than 10 and shall include flashovers in the protection system at the following nominal voltages: 200 kV, 250 kV, 300 kV, 350 kV, 400 kV, 450 kV, 500 kV.

4.4.9.3 Based on the data obtained from 4.4.9.1 and 4.4.9.2, the contractor shall set or adjust the protection system to meet the requirements of this specification.

4.4.10 60 Hz dry visual corona test. The 60 Hz dry visual corona test shall be conducted on the base insulator assembly under dry conditions in accordance with the visual corona test of ANSI C29.1 except as otherwise specified herein.

4.4.10.1 The Government reserves the right to verify the visual observation through alternate means.

4.4.11 Radio influence voltage test. The radio influence voltage test shall be conducted on the base insulator assembly in accordance with ANSI C29.1 except as otherwise specified herein.

4.4.12 60 Hz flashover mode test. The 60 Hz flashover mode test shall be conducted on the base insulator assembly with the included protection system at the final setting specified by the contractor which will allow continuous operation at 300 kV rms at 60 Hz without electrical flashover under the requirements of this specification and shall be tested as follows:

4.4.12.1 The 60 Hz dry flashover voltage test shall be conducted on the system in accordance with ANSI C29.1 except as otherwise specified herein. Flashover shall occur in the protection system as designed and not in other areas of the base insulator assembly.

4.4.12.2 The impulse flashover voltage test shall be conducted on the system in accordance with ANSI C29.1 except as otherwise specified herein. Flashover shall occur in the protection system as designed and not in other areas of the base insulator assembly.

4.4.12.3 The 60 Hz wet flashover voltage test shall be conducted on the system in acccordance with ANSI C29.1 except as otherwise specified herein. Flashover shall occur in the protection system as designed and not in other areas of the base insulator assembly.

4.4.12.4 The 60 Hz wet flashover voltage test shall be conducted on the system in accordance with ANSI C29.1 with the exception that the application of the water spray shall be in a horizontal direction except as otherwise specified herein. Flashover shall occur in the protection system as designed and not in other areas of the base insulator assembly.

4.4.12.5 The impulse flashover voltage test of ANSI C29.1 shall be conducted on the system except that the test shall be conducted under wet spray conditions as elsewhere described in ANSI C29.1 for application of water spray and in a horizontal direction. Flashover shall occur in the protection system as designed and not in other areas of the base insulator assembly.

4.4.13 60 Hz Wet withstand test. The 60 Hz wet withstand test shall be conducted on the base insulator assembly in accordance with ANSI C29.1 except as otherwise specified herein. With the protection system at the final setting specified by the contractor which will allow continuous operation at 300 kV rms at 60 Hz without flashover, the base insulator assembly shall withstand 300 kV rms at 60 Hz without flashover for a period of five minutes.

4.4.14 Shunt capacitance test. The shunt capacitance of the base insulator assembly shall be measured at 1 kHz between the base insulator assembly top adapter plate-top rainshield terminal and the base insulator assembly bottom plate or grillage.

4.4.15 Electrical grading test. The voltage distribution across the base insulator assembly tiers shall be measured in accordance with the approved procedure to determine compliance with the requirements of this specification.

4.4.16 Vlf wet flashover voltage test. The vlf wet flashover voltage test shall be conducted to flashover in accordance with ANSI C29.1 except as otherwise specified herein. If the actual wet flashover voltage of the base insulator assembly exceeds the voltage available for test, determination of the compliance of the base insulator assembly with (1) the wet flashover voltage requirements of this specification and (2) the actual wet flashover voltage of the base insulator assembly shall be by application of the available voltages to insulator tier(s). The water spray shall be in a horizontal direction. At the discretion of the Government test director, additional tests with the water spray fixed at application angles from vertical downward to horizontal may be conducted.

4.4.17 Vlf dry flashover voltage test. The vlf dry flashover voltage test shall be conducted to flashover in accordance with ANSI C29.1 except as otherwise specified herein. If the actual dry flashover voltage of the base insulator assembly exceeds the voltage available for test, determination of the compliance of the base insulator assembly with (1) the dry flashover voltage requirements of this specification and (2) the actual dry flashover voltage of the base insulator assembly shall be by application of the available voltages to insulator tier(s).

4.4.18 Vlf continuous wet withstand voltage test. The test voltage shall be slowly raised to a level of 300 kV rms and maintained at that level during the test period. Waterspray application shall be at a rate not to exceed 0.2 inch per minute over the projected area of the insulator and will be varied in any direction from vertical downward to horizontal. The base insulator assembly shall withstand the applied voltage for a minimum period of 60 minutes without flashover except due to overvoltages in excess of the wet flashover voltage test level. Provision shall be made for detecting the presence of spurious signals, transients and overvoltages. In the event flashover not due to spurious voltages occurs, the probable reason for the

flashover shall be determined, alterations made as required, and the test repeated up to a maximum of five trials. The base insulator assembly shall operate without interruption under test conditions for 60 minutes after application of full test voltage or it shall be rejected.

4.4.19 Vlf dry corona test. The vlf dry corona test shall be conducted in the time period from two hours after local sunset to two hours before local sunrise. Corona onset and extinction shall be measured. The test voltage shall be increased until corona is clearly detectable. The voltage at which corona is first detectable shall be taken as the corona onset voltage. The test voltage shall be slowly reduced until corona is no longer detectable. This voltage shall be considered to be the corona extinction voltage. Failure to attain operation at 285 kV rms onset and extinction voltage test conditions shall result in rejection of the base insulator assembly. The Government reserves the right to verify these measurements through alternate means.

4.4.20 Vlf wet corona heat rise test. The vlf wet corona heat rise test shall be conducted in the time period from two hours after local sunset to two hours before local sunrise. The base insulator assembly shall be operated at 300 kV rms under the water spray conditions of 4.4.18 until all parts have reached a stabilized temperature. Immediately after stabilization, the heat rise of the surfaces of the ceramic bodies of the base insulator assembly shall be measured in regions where corona has occurred. Temperature rise in excess of 30°C above ambient shall result in rejection of the base insulator assembly.

4.4.21 Vlf dry heat rise test. The vlf dry heat rise test shall be conducted under dry conditions at 300 kV rms at a test frequency as close to 30 kHz as available. The base insulator assembly shall be operated in still air (less than 5 mph wind) until all parts have reached a stabilized temperature. Measurements of hot spot temperatures of the ceramic bodies shall be made and recorded from the initial application of the 300 kV rms voltage until ceramic body hot spot temperatures are reached which do not vary more than ±3°C for one hour. Temperature rise in excess of 30°C above ambient at any point on the insulator ceramic body(s) shall result in rejection of the base insulator assembly.

4.4.22 Vlf flashover mode test. The vlf flashover mode test shall be conducted in accordance with ANSI C29.1 except as otherwise specified herein. The base insulator assembly with the protection system shall be tested at the final setting specified by the contractor (see 3.8.5.5.1). In the event that voltages high enough to cause flashover for the final setting specified by the contractor are not available the protection system settings shall be changed such that flashover occurs.

4.4.22.1 A dry flashover voltage test shall be conducted on the system. Flashover shall occur in the protection system and not in other areas of the base insulator assembly.

4.4.22.2 A wet flashover voltage test shall be conducted on the system. The application of the water spray shall be in a horizontal direction. Flashover shall occur in the protection system and not in other areas of the base insulator assembly.

4.4.23 Vlf interruption test. The base insulator assembly with the protection system shall be tested at the final setting specified by the contractor (see 3.8.5.5.1). A vlf voltage of 250 kV rms shall be applied to the base insulator assembly and maintained for 24 hours. During this 24 hour period normal variations in atmospheric pressure and temperature will obtain, but humidity in the area around the base insulator assembly will be varied. The number of interruptions of vlf transmission (see 6.4.12) shall be determined and shall be not greater than 12 in the 24 hour time period. If the number of interruptions exceeds 12, the protection system shall be examined, modified, and retested up to a maximum of five trials to meet the requirements of this specification. A means of monitoring the presence of any spurious voltages in excess of 7 kV peak shall be provided.

4.4.24 Dust test. One insulator unit shall be tested in accordance with Method 510 of MIL-STD-810, except that the maximum temperature shall be 50°C. The surface examination test of 4.4.1 shall be performed. Failure to meet the requirements of the surface examination test shall result in rejection of the insulator unit design.

4.4.25 Temperature shock test. One insulator unit shall be subjected to the following temperature cycle:

(a) Starting at ambient room temperature, decrease the room temperature at a rate of 25°C per hour until -25°C $\pm$ 2°C is reached, and hold at that temperature for four hours.

(b) Increase room temperature at a rate of 25°C per hour until 50°C $\pm$ 2°C is reached, and hold at that temperature for four hours.

(c) Reduce room temperature at a rate of 25°C per hour until 25°C $\pm$ 2°C is reached, and hold at that temperature for one hour.

MEGATEK CORPORATION

FINAL REPORT

Title	:	Testing of a Controlled Conductivity Water Source as Used in Testing Base Insulator Characteristics for VLF Transmitting Antennas
Number	:	R2005-001-F-1
Contract No.	:	N00123-75-C-0328
NELC Task	:	MEG TA-001
Date	:	15 December 1974

Submitted to:

Naval Electronics Laboratory Center
Code 2160
San Diego, California 92152

MEGATEK CORPORATION

FINAL REPORT

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Date	:	15 December 1974

Submitted to:

Naval Electronics Laboratory Center
Code 2160
San Diego, California 95125

Prepared by

Calvin J. Pitt

BACKGROUND

For wet testing of high voltage insulators, considerable water is used of a lower conductivity than obtainable in ordinary city tap water. In order to obtain the proper conductivity or resistivity, it is necessary to blend city water with distilled or deionized water. For testing insulators, 18,000 ohm cm^3 water is required. At the Lualualei Test Facility, distilled water was trucked 40 miles from the Naval Shipyard; and delivery at the proper time was not ensured. At the Lualualei Test Facility, the city water had a resistivity of 4,000 ohm cm^3 in January 1974, and 1,400 ohm cm^3 in July 1974. In January 1974, tests were made to determine if a deionizing system would be practical.

THEORY OF OPERATION

Two types of resin are necessary to deionize water. These resins may be mixed or used separately. When used separately, the water is first passed through the Cation-absorbing resin and then through the Anion resin. The resistivity of the water used to test insulators is much lower than the water from either the mixed bed or separate bed system. The mixed bed system produces the highest resistivity water, but the separate bed system produces the greater volume of usable water. This is due to reactions between the resins in the mixed bed system.

The following reaction takes place in the Cation resin:

$CaSO_4$	+	$2R : SO_3H$	$\rightarrow$	$R \cdot SO_3Ca$	+	H_2SO_4
Calcium Sulfate		Cation Exchange Resin		Calcium Exchanged Resin		Sulfuric Acid

The reaction for the Anion resin is as follows:

H_2SO_4	+	$2R_4NOH$	$\rightarrow$	$(R_4N)_2SO_4$	+	$2H_2O$
Sulfuric Acid from Cation Reaction		Anion Exchange Resin		Anion Exchanged Resin		Water

By the use of the Cation and Anion resin, both ions are absorbed resulting of only water from the reaction. These reactions are reversible.

city of the mixed bed system. This reduction of capacity of separate bed systems is compensated by not having to separate the resins when they are rejuvenated. Also, the resin is only supplied in 3 cu feet lots of each type. The manufacturer supplied the Cation resin activated and the Anion resin in the deactivated state.

The only water aspirators available in the Hawaiian Islands were too small to do a complete reaction of the Anion resin. Only 50% activation of this resin was possible. With 1,400 ohm cm^3 water, the 50% activated system produced 2,000 gallons of usable water. With completely activated resin, 4,000 gallons of water at a flow rate of 12 gallons/minute may be produced.

RECOMMENDATION

It is recommended that the system be modified slightly to improve the rejuvenation process. This may be done by replacing the water aspirators with Cole-Parmer Metal-Less Magnetic Drive Centrifugal Pumps No. 7004-54. Figure 2 is the modified flow diagram, and Table III gives the system valve functions. With the above pumps, the rejuvenation time will be approximately 30 minutes, and the system will produce 4,000 gallons of satisfactory water.

The pumps may be obtained from the Cole-Parmer Instrument Company, 7425 North Oak Park Avenue, Chicago, Illinois 60648 - telephone (312) 647-0272.

A resistivity metering circuit has been developed. This will improve the mixing process at values of resistivities in the 18,000 ohm cm^3 range.

Table I

Time	Barnstead Meter Megohms	NELC Meter Megohms	Flow Meter Gallons/Hr.	Gallons Processed
0747	7.4	6	30	
0803	15	6.2	30	
0837				22.36
0839	17	5.7	30	
0932				47.03
0935	16.5	5.7	30	
1032				73.99
1035	7.5	2.75	30	
1052	3.0	2.3	30	82.88* Measurir tank emp
1330	1.5	1.01	30	23.67
1350	.45	.38	30	
1430	.12	.11	30	48.66
1530	.036	.035	30	74.64
1547	.021	.025	30	81.54*

*Total gallons processed 82.88 + 81.54 = 164.42 gallons by .0717 cu feet of mixed bed resin. Gallons processed per cu feet of resin = $\frac{164.42}{.0717}$ = 2,293 gallons.

Figure I EXPERIMENTAL DEIONIZED WATER SYSTEM FLOW DIAGRAM

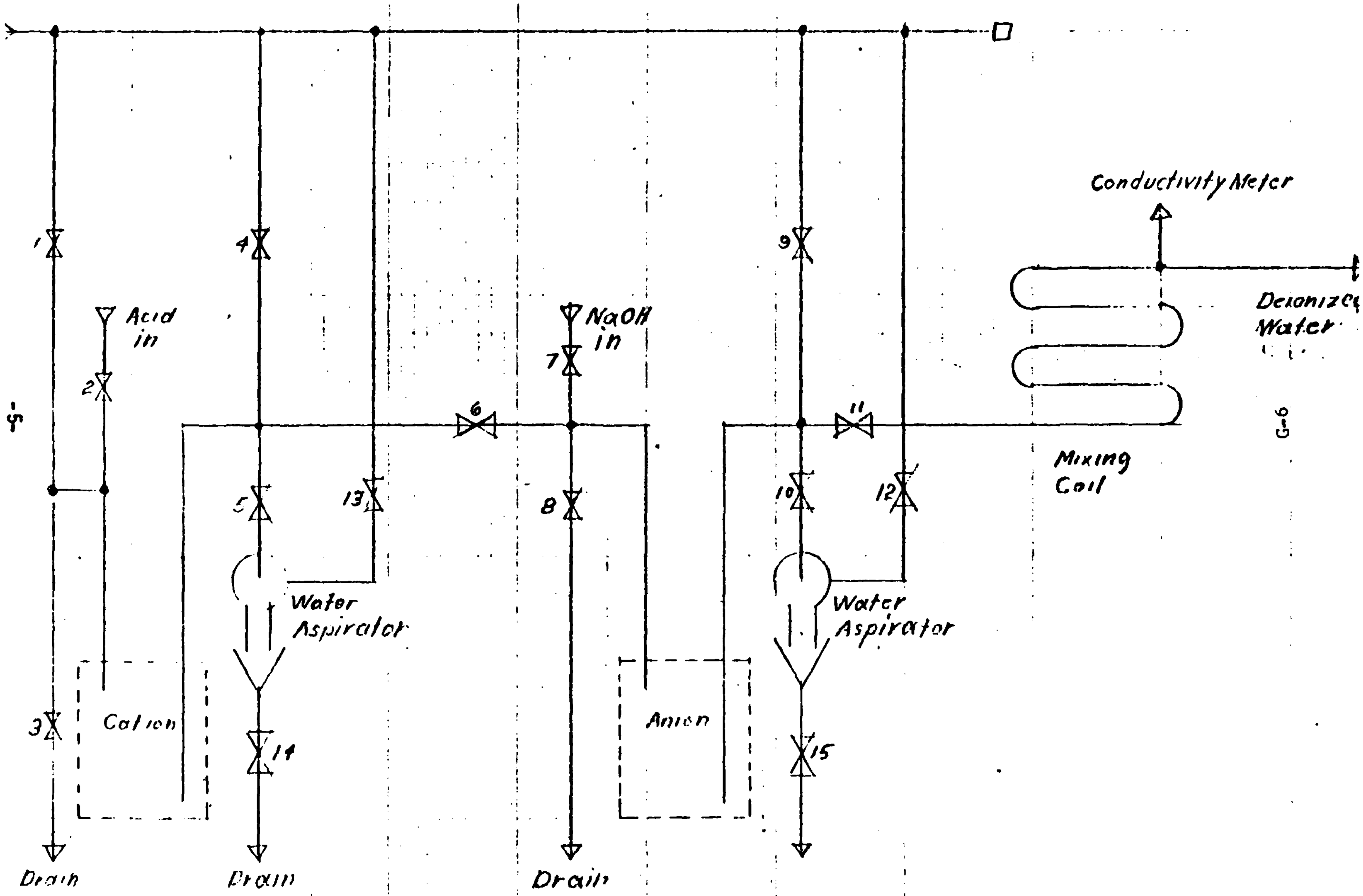

Table II

EXPERIMENTAL SYSTEM FUNCTION

To Rejuvenate Cation

Close V_1, V_3, V_4, V_6

Open V_2, V_5, V_{13}, V_{14}

To Back Wash Cation

Close V_1, V_2, V_5, V_6, V_{13}, V_{14}

Open V_3, V_4

To Use Deionized Water

Close V_3, V_2, V_4, V_5, V_{13}, V_7, V_8, V_9, V_{10}, V_{12}, V_{14}

Open V_1, V_6, V_{11}

To Rejuvenate Anion

Close V_6, V_8, V_9, V_{11}

Open V_9, V_{10}, V_{12}, V_{15}

To Back Wash Anion

Close V_6, V_7, V_{10}, V_{11}, V_{12}, V_{15}

Open V_8, V_9

Figure 2 REVISED DEIONIZED WATER SYSTEM FLOW DIAGRAM

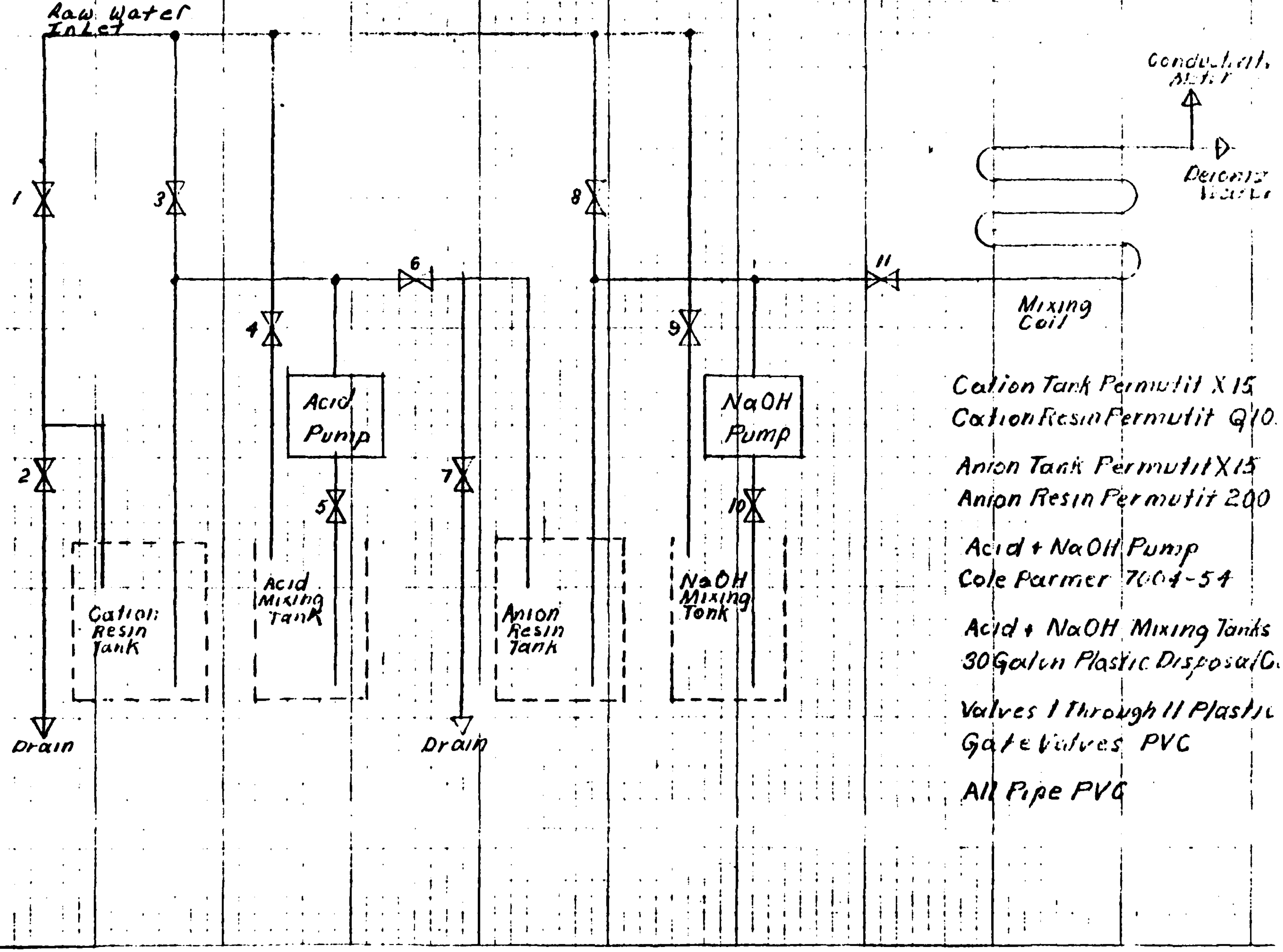

Table III

REVISED SYSTEM FUNCTION

To Rejuvenate Cation Resin

Close V_1, V_3, V_4, V_6

Open V_2, V_5

Activate Acid Pump

To Wash Cation Resin

Close V_1, V_4, V_5, V_6

Open V_3, V_2

To Rejuvenate Anion Resin

Close V_6, V_8, V_9, V_{11}

Open V_7, V_{10}

To Wash Anion Resin

Close V_6, V_9, V_{10}, V_{11}

Open V_7, V_8

To Fill Acid Tank

Close V_5

Open V_4

To Fill NaOH Tank

Close V_{10}

Open V_9

To Operate Deionized System

Close V_2, V_3, V_5, V_7, V_8, V_{10}

Open V_1, V_6, V_{11}

NOTE: Acid and NaOH tanks may be filled and mixed while system is in operation.

NAVAL ELECTRONICS LABORATORY CENTER
271 CATALINA BOULEVARD
SAN DIEGO, CALIFORNIA 92152
714-225-6011
AUTOVON 952-1011

IN REPLY REFER TO:
B223
ANS:~~bsb~~ lla
Ser 2100-261
8 Nov 73

From: Commander, Naval Electronics Laboratory Center
To: Commander, Naval Electronic Systems Command (Code PME-117)

Subj: VLF HV insulator test pass criteria

Ref: (a) NELC ltr B223 ANS:bsb ser 2100-260, encl (1) of 29 Oct 1973
(b) NAVELEX contract spec I-157 of 16 Jul 1973 and addendum 3 of 27 Aug 1973
(c) Fonecons btwn W. E. Morris, L. C. Hice/CSC and A. N. Smith/ NELC of 25 and 29 Oct 1973

1. Reference (a) is the test plan for conducting measurements of flash-over and withstand characteristics of candidate Base Insulator Assemblies (BIAs) that are being considered as alternate or interim "fixes" for VLF antennas at Lualualei and Annapolis pending the availability of new insulators under procurement under reference (b). Reference (b) gives the pass criteria for the new insulators, but reference (a) states that the alternate BIA's will have their characteristics determined by the tests without relating results to performance that will be required in order for these assemblies to be regarded as satisfactory.

2. Reference (c) describes the desired performance in the following terms:

a. Annapolis:

Radiated power shall be 400 kW for a megawatt into the antenna system at 21.4 kHz; this corresponds to a tower base voltage of 206 kV.

b. Lualualei:

Radiated power shall be 600 kW for a megawatt into the antenna system at 23.5 kHz; this corresponds to an East tower base voltage of 221 kV.

The radiating system shall meet a required reliability of performance described as 1 hour wet withstand for the insulators themselves without protective devices, and a maximum allowable 12 interruptions per 24 hour operating period due to activation of the protective devices from any cause regardless of weather conditions.

3. For the new insulators under procurement, the pass criteria that allow the requirements of paragraph 2 to be met are expressed in terms of minimum allowable flashover voltages and withstand criteria into which are included substantial safety factors. In addition, a 30° C heat rise limit over ambient temperatures must also not be exceeded during wet operation with corona flares on the porcelain from the hardware.

4. Since the procurement specifications under which the alternate BIA's were purchased are different from reference (b), the actual safety factors and indeed performance limits of these units must be regarded as at the present time unknown. Accordingly, criteria must be defined under which a candidate assembly will be regarded as capable of yielding the performance of paragraph 2. These criteria are the following:

a. Regardless of wet- or dry-flashover, the candidate BIA for alternate use at Annapolis will be considered electrically satisfactory if:

(1) Without protective devices, it successfully passes a horizontal spray wet withstand test for one hour at 28.5 kHz and does not exceed the 30° C temperature rise criterion of reference (b) at an operating voltage of 206 kV. Wet withstand may also include application of packed crushed ice.

(2) With protective devices it satisfies the above requirement and in addition under actual weather conditions including a one hour period of rain the protective devices do not cause more than twelve interruptions in a 24 hour period.

b. Regardless of wet- or dry-flashover, the candidate BIA for alternate use at Lualualei will be considered electrically satisfactory if:

(1) Without protective devices, it successfully passes a horizontal spray wet withstand test for one hour at 28.5 kHz and does not exceed the 30° C temperature rise criterion of reference (b) at an operating voltage of 221 kV. Wet withstand may also include application of surface dust and pasture debris.

(2) With protective devices it satisfies the above requirement and in addition under actual weather conditions including a one hour period of rain, the protective devices do not cause more than twelve interruptions in a 24 hour period.

c. Actual wet a[illegible] ry flashover and corona extinction values as well as observed withsta[illegible] limits will be measured and allowable antenna system performance will be calculated for these limits.

B223
ANS:bsb
Ser 2100-261

5. The pass criteria of paragraph 4 are herewith transmitted as addenda to reference (a) and should be attached thereto.

Copy to:
CNO
COMNAVTELCOM
COMSUBPAC
NAVELEX (Code 09, PME-119, 05)
NAVELEXWASHDIV
NAVSEEACTPAC
NAVFACENGCOM (Code 09A, PC-6)
NAVFACENGCOMCHESDIV
PACNAVFACENGCOM
OICC MIDPAC
Science Applications, Inc.
Electrospace, Inc.

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714-225-6011
AUTOVON 952-1011

IN REPLY REFER TO:
B223
ANS:~~bsb~~ llr
Ser 2100-260
8 Nov 73

From: Commander, Naval Electronics Laboratory Center
To: Commander, Naval Electronic Systems Command (Code PME-117)

Subj: Test plan for use of Lualualei facility in alternate base insulator assembly and isolation unit investigations

Ref: (a) NAVELEX Spec I-157 of 19 Jul 1973 and Statement of Work, ser 311312
(b) NAVELEX ltr 51052:FRS:ejr ser 151-510123 of 4 Sep 1973
(c) NAVELEX 011715Z May 1973
(d) NAVELEX ltr 3930/SPECOM ser 239 PME-117-22 of 17 Sep 1973
(e) NAVELEX 242119Z Aug 1973
(f) CNO 292134Z Aug 1973
(g) NAVELEX ltr 3930/SPECOM ser 257 PME-117-223 of 21 Sep 1973

Encl: (1) Test Plan for Establishing VLF Characteristics of Alternate Base Insulator Assemblies and Isolation Units

1. References (a) and (b) together establish the desired electrical characteristics of new Base Insulator Assemblies (BIAs) presently contracted for with Continental Electronics Manufacturing Co. of Dallas, Texas by NAVELEX. The specification establishes the requirement to test these assemblies at voltages up to 500 kilovolts for acceptance. References (c) and (d) establish NELC as the agent for NAVELEX to design, construct, and test the test facility at NRTF Lualualei and to act as test director for carrying out tests on BIAs under procurement.

2. References (e) and (f) establish the further requirement to consider certain existing insulator designs as possible alternate approaches to new procurement, based on existing availability of the units; and requires that they be tested at VLF using procedures similar to those called out in references (a) and (b). These tests are to be carried out on the high voltage test facility at Lualualei, under NELC as test director.

3. Reference (g) establishes the performance schedule of construction and test of the facility, and of the subsequent insulator tests. The submission required therein, called out as items 14 and 15 in the

B223
ANS:bsb
Ser 2100-260

Lualualei portion of the schedule, is the Test Plan for carrying out the electrical performance measurements on alternate BIAs. Enclosure (1) is herewith submitted in fulfillment of this requirement. It does not address the testing of the new permanent BIAs.

4. Message or letter approval of this plan is requested.

Copy to:
CNO
COMNAVTELCOM
COMSUBPAC
NAVELEX (Code 09, PME-119, 05)
NAVELEXWASHDIV
NAVSEEACTPAC
NAVFACENGCOM (Code 09A, PC-6)
NAVFACENGCOMCHESDIV
PACNAVFACENGCOM
OICC MIDPAC
Science Applications, Inc.
Electrospace, Inc.

Fig. 4

TEST PLAN FOR ESTABLISHING VLF CHARACTERISTICS OF ALTERNATE BASE INSULATORS AND ISOLATION UNITS

A. N. Smith
23 October 1973

1. INTRODUCTION AND REFERENCES

This test plan addresses the testing of the following insulator assemblies: the tower base insulator for the OMEGA navigation station in Argentina; the existing Lapp 9-cone tower base insulator as presently configured for Lualualei and Annapolis, combined with certain modifications thereto; and two configurations of the Lapp insulated-shaft motor-generator power unit for insulated tower lighting. It generally includes all tests required by the specification describing the new Continental Electronics base unit presently under procurement, but does not regard the voltage levels of that specification as requirements, but as guides and design goals. In addition, certain other tests will be run to establish the behavior of the modification to the Lapp assembly suggested by Science Applications, Inc. under adverse environmental conditions.

This document refers to, makes use of, and herewith incorporates as an integral part of its content, material from the following:

a. NELC ltr B223 ANS:bsb ser 2100-169 of 6 June 1973, Enclosure (2) Lualualei High Voltage Test Circuit Design Drawings.

b. NELC ltr B223 ANS:bsb ser 2100-171 of 11 June 1973, Enclosure (1) Basis for Lualualei High Voltage Test Circuit Design.

c. NELC ltr B223 ROE:jcs ser 1300-24 of 24 January 1973, Enclosure (1) Test Plan for High Voltage Tests of OMEGA Tower Type Base Insulator.

d. NELCEN 121909Z Sep 1973 to NAVELECSYSCOM

e. USAS/IEEE C68.1/No. 4, 1968/Apr 1969: USA and IEEE Standard Techniques for Dielectric Tests.

f. USAS C29.1 - 1969 (R1969) C29.1a - 1971: USA Standard Test Methods for Electrical Power Insulators.

In addition, it is to be noted that some of the suggestions contained in the following listed messages have been incorporated, and other tests mentioned therein will be attempted if time permits: COMNAVELECSYSCOM 302306Z Jan 1973; NAVCOMMSTA HONO 060300Z February 1973; COMNAVELECSYSCOM 100525Z February 1973. The test configuration for the Lapp insulator is described in NAVCOMMSTA Hono 281209Z Sep 73 to NAVELECSYSCOM.

Although commonly used as a portion of the pass criteria, NEMA Pub No. 107-1964, Methods of Measurement of Radio Influence Voltage (RIV) of High Voltage Apparatus, this document is not a part of the present test plan, inasmuch as the present procurement specification requires no rfi tests to be performed except in connection with the 60 Hz qualification tests.

With a few exceptions, detailed manipulative procedures are not repeated in this text where they are adequately described in the above reference list. Instead, specific reference is made in the plan to appropriate paragraphs.

2. TEST PLAN OUTLINE AND MILESTONE DATES

The following dates are defined for the various tests in NAVELECSYSCOM ltr 3930/SPECOM ser 257 PME-117-223 of 21 September 1973. In a separate column have been included what are regarded as realistic dates for actual testing in view of occurrence of holidays and availability of personnel. The detailed scheduled dates have been compiled with these probable realistic dates in mind.

TABLE 1

Test (Major Category)	Sched. Dates	Realistic Dates
Test Facility Prelim Checkout	1 - 10 Nov 73	1 - 10 Nov 73
Low Level		1 - 5 Nov 73
High Level		5 - 10 Nov 73
Argentina OMEGA BIA tests	10 - 24 Nov 73	11 - 20 Nov 73
2-Tier Isol Unit	24 Nov 73 - 4 Dec 73	26 Nov 73 - 4 Dec 73
Lapp BIA Test	4 Dec 73 - 10 Jan 74	5 Dec 73 - 21 Dec 73 2 Jan 74 - 10 Jan 74
3-Tier Isol Unit	10 Jan 74 - 15 Jan 74	11 Jan 74 - 15 Jan 74
Tower BIA Heat Rise Tests	15 Jan 74 - 2 Feb 74	16 Jan 74 - 2 Feb 74
New Continental BIA Tests	7 May/5 Jul 74 - 7 Jul/7 Sep 74	

The above constitutes in broad outline the test sequence by component to be tested. The following listing gives the individual test categories and estimated dates.

TABLE 2

Maj. Category	Title	Alpha-numeric Desig.	Dates
Test Fac. Checkout	Water System	F-1	1 Nov or prior
"	Low Level Impedance	F-2	1-3 Nov 73
"	Current Meter Cal.	F-3	4 Nov 73
"	Voltage Distribution	F-4	5 Nov 73
"	CCO Checkout	F-5	5-6 Nov 73
"	Corona Detection	F-6	6-7 Nov (Night)
"	Protective Gap Calibration, Heat Run	F-7	8 Nov 73
"	Final CCO setting	F-8	9 Nov 73
"	Public Demonstration and Slide Show	F-9	9 Nov 73 (Night)
Arg. BIA Tests	Capacity	A-1	10 Nov 73
"	Grading	A-2	10 Nov 73
"	Heat Rise	A-3	12 Nov 73 (Night)
"	Corona Inception	A-4	12 Nov 73 (Night)
"	Withstand	A-5	12-13 Nov 73 } Optional day/night
"	Flashover	A-6	13 Nov 73 } Optional day/night
"	External Gap Calib.	A-7	13-14 Nov 73
"	Intratier Gap Calib.	A-8	17-18 Nov 73
"	Tests A-1, A-2, -4, -5, -6 with External Gap only will have suffix designator E, e.g., A-1-E		14-17 Nov 73
	Tests A-1-E, etc., with both External and Internal gap will have suffix designator EI, e.g., A-1-EI	8	18-20 Nov 73

NOTE: Some of the calibration tests on gaps may be conducted at night. Heat rise tests with gaps will not be done.

2-Tier Isol Unit in Parallel with Arg. BIA	Capacity	I_2-1-A	27 Nov 73
	Corona Inception	I_2-4-A	27 Nov 73 (Night)
	Withstand	I_2-5-A	28 Nov 73

TABLE 2 (CONT)

Maj. Category	Title	Alpha-numeric Desig.	Dates
2-Tier Isol Unit in Parallel with Arg. BIA	Flashover	I_2-6-A	29 Nov 73
2-Tier Isol Unit - No BIA present	Capacity	I_2-1-I	30 Nov 73
	Corona Inception	I_2-4-I	30 Nov 73 (Night)
	Withstand	I_2-5-I	1 Dec 73
	Flashover	I_2-6-I	3 Dec 73

NOTE: Grading and heat rise will not be done

Maj. Category	Title	Alpha-numeric Desig.	Dates
Lapp BIA Tests Stock, with NELC R. S. & NELC Intratier gaps, w external gap. Interiors clean, sealed, pressurized. No tests to be conducted without NELC rainshield (R.S.)	Capacity	L-1	5 Dec 73
	Grading	L-2	5-6 Dec 73
	Heat rise	L-3	6-7 Dec 73 (Night)
	Corona Inception (tier by tier and whole unit)	L-4	7-8 Dec 73 (Night)
	Withstand (w & w/out intr. gap)	L-5	10 Dec 73 (Optional day/night)
	Flashover (w & w/out intr. gap)	L-6	11-12 Dec 73 (Optional day/night)
	External Gap Cal.	L-7	Unsched
	Internal Gap Cal.	L-8	Unsched

L-7 and L-8 are not scheduled tests. Settings will be made according to NELC ltr rpt 1300-543 "Technical Report of VLF Transmitter Antenna Base Insulator Fix Investigation" of 16 Oct 1972 and to NELC ltr B223 ser 2100-523 ANS:bsb of 12 Nov 1972. If different settings are required, L-7 and -8 will be conducted as necessary and when convenient.

Maj. Category	Title	Alpha-numeric Desig.	Dates
With Field-shaping rings, external surfaces dry	Capacity	L-1-F	13 Dec 73
	Grading	L-2-F	13-17 Dec 73
	Corona Inception	L-4-F	18 Dec 73 (Night)
	Withstand (w & w/out intr. gap)	L-5-F	19-20 Dec 73
	Flashover (w & w/out intr. gap)	L-6-F	21-22 Dec 73
With Field-shaping rings, external surfaces greased	Corona Inception	L-4-FG	2 Jan 74 (Night)
	Withstand (w & w/out intr. gap)	L-5-FG	3 Jan 74 (Optional day/night)
	Flashover (w & w/out intr. gap)	L-6-FG	4 Jan 74 (Optional day/night)

TABLE 2 (CONT)

	Title	Alpha-numeric Desig.	Dates
..s ..-shaping ..urfaces ..d, and using ..caminants in ..ddition to water	Corona Inception	L-4-FGC	
	Withstand (w & w/out intr. gap)	L-5-FGC	7-9 Jan 74 inclusive
	Flashover (w & w/out intr. gap)	L-6-FGC	
3-Tier Isol Unit with Lapp BIA	Capacity	I_3-1-A	11 Jan 74
	Corona Inception	I_3-4-A	11 Jan 74 (Night)
	Withstand	I_3-5-A	11 Jan 74
	Flashover	I_3-6-A	12 Jan 74
without Lapp BIA, in isolation	Capacity	I_3-1-I	12-13 Jan 74
	Corona Inception	I_3-4-I	13 Jan 74 (Night)
	Withstand	I_3-5-I	14 Jan 74
	Flashover	I_3-6-I	14-15 Jan 74
Tower BIA Heat Rise Tests This series of tests is to be run by NAVSEEACTPAC, with NELC as consultant-observer. This test plan does not address these tests.		(Night)	15 Jan-2 Feb 74 (Night)

NOTE: Dates chosen for the tests in the above schedule allow for no Sunday work, although they require Saturday work. The time periods of 21 through 26 November and 23 December through the first half of 2 January 1974 are uncommitted due to Thanksgiving and Christmas holidays. The following days, or part thereof, are reserved for moving in heavy equipment or assemblies, and assembly work:

TABLE 3

Argentina Insulator Assembly	Prior to 1 Nov 73
2-Tier Isol Unit Move-in	26 Nov 73
Argentina Insulator Dissassembly and move-out	30 Nov 73 (Morning)
2-Tier Isolation Unit move-out	4 Dec 73
Lapp BIA Assembly	4-5 Dec 73
Final Fit and Place Shaping Rings	Late 12 Dec 73, Early 13 Dec 73
Lapp BIA Dissassembly and move-out	Late 12 Jan 74
3-Tier Isol Unit move-in	10 Jan 74
3-Tier Isol Unit move-out	After 15 Jan 74

It is also noted that in the above schedule the time period 13 December through 16 December 1973 is reserved for travel by the NELC test director to the Final Design Review for the new Continental BIA, scheduled at present to take place on 14 December 1973 at Dallas. If this event is rescheduled, the above dates will shift accordingly. The completion date for the entire sequence will not be affected. Finally, it is to be remarked that no allowance has been made for transmitter down time for any reason, nor has any allowance been made for extension or contingencies due to weather.

3. LOGISTICS AND HANDLING SUPPORT REQUIREMENTS

The physical setting up and removal of the test objects as well as the conduct of certain tests will require special support on the part of several organizations. This section identifies requirements and where possible establishes end dates for delivery. It does not attempt to define start dates of preparation, since that is a proper function for the agency involved to define for itself to meet the required delivery date. The listing is keyed to the test designations of Section 2, and names the agency tasked. It is assumed NELC conducts all tests. The following abbreviations have been employed:

NAVCOMMSTA

TABLE 4

NAVCOMMSTA HONO	NCS
Public Works Riggers	PWCR
NRTF Lualualei	NRTF
NAVSEEACTPAC	NSP
Naval Electronics Lab Ctr	NELC
Science Applications, Inc.	SAI
Continental Electronics Mfg Co.	CEMCO

TABLE 5

Test	Agency	Requirement	Dates
F-1	NRTF/NSP	Set up water system, run pump, provide baffle for determining density distr.	Prior to 1 Nov 73
F-1	NELC	Measure delivery rate and density distr.	Prior to 1 Nov 73
F-2	NCS/PWCR	Make & break helix connection. Provide fork lift access to capacitor connectors.	1-3 Nov 73
	NRTF	Technician help in circuit manipulation.	
	NSP	Provide further instrumentation: Boonton Q meter, 260; HP 302 Wave Analyzer; 422 Scope, if available; HP current probe	

TABLE 5 (CONT)

Test	Agency	Requirement	Dates
F-1	NELC	Measure delivery rate and density distribution.	Prior to 1 Nov 73
F-2	NCS/PWCR	Make & break connection. Provide fork lift access to capacitor connectors.	1-3 Nov 73
	NRTF	Technician help in circuit manipulation.	
	NSP	Provide further instrumentation: Boonton Q meter, 260, HP 302 Wave Analyzer 422 Scope, if available, HP current probe Access to top of coils (24' free ladder)	
	NRTF	Access to Helix house and lights to illuminate test circuitry.	
F-3	NRTF	Use of HiPot, and tech help at console	4 Nov 73
	NSP	Access to outside coil top HP RF current probe if available	
F-4	NSP	Access to top of outside coils	5 Nov 73
	NRTF	Technician help in low power transmitter runs	
F-5	NRTF	Adapts and places CCO and adjusts	6 Nov 73
F-6	NRTF	Technician help to run transmitter Extra observers	6 Nov 73
	NSP	Extra observers 10 pr binoculars, 7 x 50 min. Arrange for materiel support in event of necessity for circuit mods. Thermotabs if required for thermal rise detec.	
F-7, -8	NRTF	Run transmitter, make final CCO adj.	8 Nov 73
	NSP	Ladder access to all parts of coils. Extra observers; ladder access to large sphere gap.	
F-9	NRTF/NCS	Auditorium, publicity slide projector, technicians to run transmitter, water system, safety observer; observer seats (guest)	9 Nov 73
	NCS/PWCR	Set up dummy test object and HV connector (may make use of tripod of stick insulators or of platform generator posts)	9 Nov 73
A-1	NCS/PWCR	Set cribbing for mock-up grillage	Prior to 10 Nov
	NSP	Cover grillage with hardware cloth	10 Nov 73
	NCS/PWCR	Uncrate, set Test Object, Set up HV test lead	10 Nov 73

TABLE 5 (CONT)

Test	Agency	Requirement	Dates
A-1 Cont	NSP/NELC	Assemble rain shield, lower corona ring	
	NCS/PWCR	Provide foundation for external gap	
	NSP	Provide hardware for mounting intratier gap per NELC design. Arrange for UT tests if NAVELEX tasking requires. Provide access to top of HV coils, extra instrumentation, per F-2	Prior to 10 Nov
A-2	NRTF	Run transmitter	10 Nov 73
	NCS/PWCR/ NELC	Install HV lead from capacitor	10 Nov 73
	NSP	Assist in mounting gaps for grading meas.	10 Nov 73
A-3	NRTF	Run transmitter, water system	11-12 Nov 73
	NSP	Provide personnel and means for heat rise detection	
A-4 -5 -6	NRTF	Run transmitter, water system	12 Nov 73
	NSP	Provide extra observers and detection means	
A-4-E&E-I -5 -6	NSP	Provide sea water (20 gal) and 2 tons crushed ice (about 3 yards) if contamination tests are run (two occasions)	13 Nov 73 and 17 Nov (approx)
I_2-1-A	NSP	Arrange for construction and delivery of mock-up mounting table. Access to coil.	Prior to 25 Nov
	NCS/PWCR "	Set up mock-up mounting table, bolt down Mount isol. unit on table	25 Nov 73
	NCS/PWCR & NELC	Modify HV test lead and connect to isol. unit (Provide interconnection from IU to TO)	27 Nov 73
I_2-4-A 5 6	Agencies as described in A-4, -5, -6 above		28 Nov 73
I_2-1-I	NCS/PWCR	Remove Argentina BIA from pad, recrate for shipment. Remove grillage	29 Nov 73
	NSP	Arrange for post-test UT if required. Access to top of HV coil	Prior to shipment
I_2-4-1 5 6		Agencies as described in A-4, -5, -6	30 Nov 73
L-1	NCS/PWCR	Remove 2-tier isol. unit and table.	3 Dec 73
		Assemble Lapp BIA in place	4 Dec 73
		Remove NELC rainshield from E tower and assemble to Test Object. Remove	4 Dec 73

TABLE 5 (CONT)

Test	Agency	Requirement	Dates
L-1		external rod gap from E tower, bring in. Provide mounting support for external rod gap, and mount (W type, not Lapp gap)	4 Dec 73
	NCS/PWCR & NELC	Install sealant under cone hardware as BIA is put together; seal grout and cover sealant with caulking.	4 Dec 73
	NELC & NSP/NRTS	Install vent system and test.	5 Dec 73
	SAI	Pre-fit and later install shaping rings (installation to be as scheduled below)	Prior to 3 Dec
L-2, L-3		Agencies as in A-2, A-3	5-6 Dec 73
L-4 -5 -6		Agencies as in A-4, -5, -6. Additionally, NSP assists in mounting and demounting intratier gap.	7-12 Dec 73
L-1-F through L-6-F		As in the L-series without shaping rings. Additionally, SAI installs rings to their satisfaction.	Dates as shown in section 2
L-1-FG through L-6-FG		Agencies as in the L- series. Additionally NSP/SAI/NELC grease outside of Lapp cones.	Dates as in section 2
L-1-FGC through L-6-FGC		Agencies as in the L-X-FG series. Additionally, NRTF/NCS PWCR will provide pasture debris contaminant. As option, NSP will provide salt brine, 20 gal.	Dates as in section 2
I_3-1-A through I_3-6-A		Agencies as in I_2- series Additionally, NCS PWCR remove Lapp BIA prior to I_3-1-I.	Dates as in section 2 12 Jan 74
I_3-1-I through I_3-6-I		Agencies as in I_2- series	As in sec 2

At conclusions of tests, NCS PWCR will remove and store, ready for crating, all components of BIA's that must be shipped.

4. OPERATING POSITIONS AND PERSONNEL REQUIREMENTS

During most electrical tests, the following positions will be manned:

TABLE 6

Building watchstanders (not part of tests per se)		NRTF
Transmitter operators	(2)	NRTF
Water handler Truck operator Conductivity mixer Pressure pump oper.	(1)	NRTF -
Manifold Operator	(1)	NELC or NRTF
Safety Observer	(1)	NRTF or NELC
Test Hut Observers Take data Control system (Test Director)	(2)	NELC
Logistics, Instrumentation Provides assist with special envir. conditions, provision of gaps, etc.	(1)	NSP
Riggers, when required, for test object handling	(4) min.	NCS PWCR
*Observers for special tests contamination, field shaping rings, BIA cone interior vent, transmitter mods, etc.	(4) (one from each org.)	CEMCO/SAI/LAPP/ESI

*These individuals are not active participants in running tests but provide special equipment, configurations, and consultation.

Under exceptional conditions, such as when the test facility itself is under acceptance tests, during the F series, more personnel will be required on a temporary basis. This will be especially true during initial corona detection and heat rise tests. During these tests as many as ten observers in the "safety observer" category will be used for visual corona detection and manual search for hot spots. Under usual test conditions, the only individuals inside the protective fence when the circuit is active will be the two observers inside the test hut, one of which will be the Test Director. All other personnel will be outside the fence. The only exception to this practice will occur possibly during corona tests on the test facility itself, F-6, and possibly during the voltage distribution measurements, F-4. All individuals other than those assigned specific positions in the numbers given above are supernumerary to the conduct of the tests, and have the position of unofficial observers only. Regardless of their Navy rank, or their position in other

.th the VLF improvement program, they will be asked to stay as ssible of the test area inside the protective fence, to vacate it ely on request from the Test Director, to refrain from asking for .cal explanations about the tests during their performance, and specifically to engage the Safety Observer in any kind of conversation or distraction during actual testing. It is understood that for the most part the test facility positions will belong to specifically assigned persons whose names will be known to the Test Director. The only two individuals that may countermand a procedure being carried out by the Test Director are the NRTF OIC and the NCS Commanding Officer; the sole function of the Safety Observer is to interrupt a test procedure in the event of unexpected emergencies or hazards arising during a test, by use of a "panic" switch. Redirection, shift of emphasis, or change of schedule will arise by mutual exchange between Test Director and NAVELECSYSCOM PME-117.

5. DESCRIPTIONS OF TESTS, PARAMETERS, METHODS

In the descriptions to follow, heavy use is made of references to detailed procedures given in the document list of Section 1. Where possible, this will be by specific paragraph.

5.1 Test Listing by Type

For convenient reference, the test categories by alphanumeric have been listed below according to the nature of the tests. The following abbreviations have been used:

TABLE 7

WFO wet flashover
DFO dry flashover
WWS wet withstand
DWS dry withstand
WCI wet corona inception
DCI dry corona inception
WCE wet corona extinction
DCE dry corona extinction
WHR wet heat rise
DHR dry heat rise
GCW gap calibration, wet } these are withstands
GCD gap calibration, dry }
GCWWS gap calibration wet withstand
GCDWS gap calibration, dry withstand
IF interruption frequency

CFO contamination flashover
CWS contamination withstand
CCI contamination corona inception
CCE contamination corona extinction

Wet flashovers and withstands may be performed with 45° plunging spray application, or with horizontal spray. In any case, for purposes of this test plan, a wet test is an active spray test. A wet corona test according to the ANSI standards is generally a drip-dry test. In this test plan a wet corona test is a spray test, but a drip-dry test may be run for comparison, time permitting. All water will be of American standard conductivity. A contamination test is in the nature of a drip-dry test or a dry test, depending on the contaminant. This is because no convenient means exists at this test facility to apply a continuous spray of a wet contaminant. The contaminants considered are:

Dry salt water and dirt

Wet salt water and dirt

Dust, manure, straw, with and without insulator surface silicone grease treatment

Shredded ice, to simulate wind-slabbed snow.

In the flashover listings below, the only F series tests are the public demonstration and the gap calibrations. This is because the corona detection tests are aimed at producing information for fixes to enable the circuit to perform corona-free up to 500 kV, rather than producing merely the existing inception or extinction limit. There are no flashover tests to be performed per se, except for informal trials with the Lapp station posts in the capacitor, but these are rated to values such that normal operating voltages are not expected to produce flashovers.

TABLE 8

WFO:	F-7, F-9; A-6, A-7, A-6-E, A-6-EI; I_2-6-A, I_2-6-I; L-6, L-6-E, L-6-EI, L-7, L-6-F, -FG, -FGC; I_3-6-A, -I.
DFO:	F-7, F-9; A-6, A-7, A-8, A-6-E, A-6-EI; I_2-6-A, -I; L-6, L-6-E, L-6-EI, L-7, L-8, L-6-F, -FG, -FGC; I_3-6-A, -I (same as for WFO). Also, A-2, A-2-E, A-2-EI and L-2, L-2-E, L-2-EI.
WWS:	F-7, F-9; A-5, A-7, A-8, A-5-E, -EI (A-7-E, -EI, A-8-E, -EI); I_2-5-A, -I; L-5, L-5-E, L-5-EI, L-7, L-8; L-5-FG, -FGC; I_3-5-A, -I.
DWS:	Same as for WWS
WCI, DCI, WCE, DCE:	F-6 (Dry only); A-4, A-4-E, A-4-EI; I_2-4-A, -I; L-4, L-4-E, -EI; L-4-F, -FG, -FGC; I_3-4-A, -I. If a dummy test object is used for demonstration, F-9 is also included.

WHR, DHR: A-3; L-3, L-3-F, -FG, -FGC (the latter three are not listed as tests in section 2, but may be added as options, time permitting).

GCD, GCW: F-7; A-7-E, -EI, A-8-E, -EI (dry only); L-7-E, -EI, and L-8-E, -EI may be added as options, time permitting.

IF: A-7-E, -EI; L-7-E, -EI

Impedance and Voltage Calibration Tests:

F-2, F-3, F-7; A-1, I_2-1-A, -I; L-1, L-1-F if used, I_3-1-A, -I

Special Facility Tests:

F-1, F-5, F-8. F-7 is run in connection with F-6

CFO: A-6 (salt water drip dry, salt water dried, dirty salt water drip dry and dry, dust, crushed ice); L-6 (salt water drip dry, salt water dry, dirty salt water drip dry, and dry dust); L-6-F, -FGC (same as L-6, additionally, use pasture and lifestock debris dry and then damp).

CWS, CCI, CCE: Same as for CFO.

5.2 Test Methods

The methods of carrying out individual types of tests are given in this section. They are listed by type of test. The test object configuration will be chosen and constructed according to the test designation. Because of the type of insulator involved, the configurations do not comply in all respects to the geometrical arrangement of high voltage connectors described in the ANSI Standards, references (e) and (f).

DFO: Dry flashovers are performed in the manner called out in ref (e) by paragraphs

1.3.1, 1.3.2: with atmospheric corrections applied by the method of paras.

1.3.4.1, 1.3.4.2, 1.3.4.3, 1.3.4.4: Dry flashovers also comply with ref (f) paragraphs

4.2.2, 4.2.3, 4.2.4.1, 4.2.4.2

WFO: Wet flashovers are performed as called out in ref (e) by paragraphs

1.3.1, 1.3.3.1 and in ref (f) by paragraphs

4.3.1, 4.3.2, 4.3.3, 4.3.4, 4.3.5. However, horizontal spray direction

will be used, and at the option of the Test Director, 45° plunging direction in some instances.

DWS: Dry withstands will be conducted as described in ref (e) paragraphs

1.2.1.2, 4.3, 4.3.1 and in ref (f) in paragraphs

4.4.2, 4.4.3, 4.4.4

WWS: Wet withstands comply with ref (e) paragraphs and ref (f) paragraphs

4.5.2, 4.5.4, 4.5.5, 4.5.6. Again, horizontal spray applications of primary interest.

Withstand procedures deviate from the ANSI standards in that they will not be 10 second withstands, but will be one hour withstands, as called out for the procurement specification for the Continental base insulators. Heat rise tests will be conducted in much the same manner as withstand tests.

DCE, WCE: Corona extinction tests, both wet and dry, will be conducted as in ref (f) paragraph 4.10.3. However, the observation will be made through 7 x 50 binoculars, using a number of observers. The tests will be spray wet tests with spray application made in the manner called out in the wet flashover and wet withstand tests. In some instances comparison will be made with drip dry corona extinction tests.

DCI, WCI: Corona inception tests will be carried out in the manner used for extinction tests, except for the reverse trend in applied voltage.

CFO, CWS, CCI, CCE: Tests with contaminated surfaces will be performed in accordance with procedures applicable to wet tests, but they will be performed as "drip dry" tests when the contaminant is wet, since there is no provision in the facility to apply a continuous stream of contaminated water or dust or pasture debris.

GCD, GCW: Rod and ball gap calibrations are carried out generally as described in the USAS Standard C68.1, ref (e). However, the geometry of the gaps used in the test facility does not comply in all respects with that described therein.

IF; Interruption frequency will be conducted as a withstand test.

In carrying out the detailed manipulative processes in the tests, the procedures outlined in ref (c) will apply with modifications to reflect the

higher reactance of the present test source circuit compared with that used before. In the present instance, the circuit impedance is such that approximately 160 amperes of rf current at a frequency of 28.5 kHz will produce 500 kV on the test object. Dry flashovers are described in section 3 of ref (c), wet flashovers in section 4, grading measurements in section 5 (these are relative comparisons of sphere gap dry flashovers), and withstands in section 6. These procedures as described comply closely with the paragraphs called out in the other two references.

The calibration tests on the facility itself are of two kinds, one to give assurance that the circuit components are not driven to perform at levels higher than is safe, and the second to provide accurate knowledge of voltages and water delivery rates. Tests F-4, F-5, F-6, and F-7 are of the first kind, while tests F-1, F-2 are of the second, F-8 is a verification that the circuit is fully functional, and test F-9 is of the same nature, as well as a public-relations effort.

5.3 Detailed Test Procedures and Sequence

This section is for two purposes. First, in Table 9, the test types have been listed by test category (alphanumeric) and in this sense the table constitutes a cross reference for Table 8. Second, the manipulative details for the F series of tests have been described. Those for the other test categories are considered to be adequately covered by material in the references appended hereto.

TABLE 9

Alphanumeric	Test Type and Sequence	Comment
A-1	Impedance and voltage calibration	By substitution and/or impedance bridge
A-2	DFO, each tier in turn at common setting	
A-2-E	DFO with external gap only, in place	Comparison between -E and -EI with test conducted without gaps should show little change
A-3	DHR, then WHR	Start with 10 min intervals, extend to 1 hour in about 3 tries. Use 250 kV as operating limit.
\-4	DCI, DCE, WCI, WCE. (CCI, CCE as options)	45° plunging, then horizontal spray application 0.2" per min. Follow with drip dry, time permitting.

TABLE 9 (CONT)

Alphanumeric	Test Type and Sequence	Comment
A-4-E, -EI	DCI, DCE, WCI, WCE	Compare formation of corona on gaps with that on insul. hardware (level of voltage)
A-5, A-5-E, -EI	DWS, WWS (May be run as CWS as option, time permitting)	Look for 1 hour limit in each case.
A-6	DFO, WFO, CFO	(see table 2 and 8 for combinations of conditions.)
A-6-E, -EI	DFO, WFO (CFO optional)	(Compare behavior and levels with A-6)
A-7	DFO, WFO Use six to ten gap settings in upward order of separation, each case. Afterward, a WWS is determined such as to yield IF of 1 hour. This test also is categorized as GCD, GCW.	Exploratory determination of appropriate protective setting to allow specified operation of BIA. Gap is left set for desired WWS.
A-8	DFO. Afterward, observation is made of behavior as WWS, but spray may or may not wet gap. Test is also categorized as GCD. Note that in Table 8 these tests appear as types A-7-E, -EI, -8-E, -EI, but these are not really separate tests.	As for A-7.
I_2- series	Replace A by I_2 where appropriate in above listing. Note that there are no grading tests or gap calibrations for the isol. unit tests. Also, there are no CFO tests.	
I_3- series	Same categories as for I_2.	
L- series	Replace A by L where appropriate in above listing. Note that CFO & CWS are <u>not</u> optional, but that gap calibrations are optional, as data already exists for them. Also, conditions for CFO tests are not the same as for the A- series. See Table 8 for the differences. In corona inception and extinction (CCI, CCE) for contaminated conditions, the tests are required, not optional. Note also repetitions as required for set-up where field shaping rings (F) and field shaping rings with greased porcelain (FG) and with greased and adhering pasture dirt (FGC) are used. Finally, in some of the latter (see Table 8) the internal ball gap system may be removed so as not to interfere with the determination of actual limits.	

TABLE 9 (CONT)

Test Type and Sequence	Comment
A special supplementary series of these tests will be run on a single tier of the insulator assembly. This will comprise all tests of this set run on the entire unit as a whole.	

In all the above, the data to be recorded are the base current meter readings, the frequency, the capacitor divider readings from the Jennings meter, if used; and the barometric pressure, dry and wet bulb readings, and relative humidity. The field-sampling tuned voltmeter readings will also be recorded and the calibration factors for this will be kept. The static capacity of the test object and high voltage capacitor will provide the information needed to calculate test voltages. The signal presentation on the oscilloscope will provide qualitative information on signal purity. Wave analyzer readings at harmonics of the test frequency will give information on distortion. It is expected, however, that since the PA grid bias supply has been filtered, and since the tubes will probably be operating in saturation in view of the employment of the bandwidth resistor, there should be little trouble with modulation of the carrier with the 180 Hz sidebands as was the case heretofore when the supply was unfiltered and the transmitter was lightly loaded.

The test facility checkout consists of nine steps, as given in Table 2. In this series of tests, more is involved than recording voltage levels, as this part of the test sequence constitutes a facility calibration. The tests are described below in the order of their performance.

Sec —

TEST F-1

Water System Test

1. Assemble water system as shown, Figure 1.

2. Fill tank with standard water:

   a. Use proportions calculated as follows:
   If k = fraction of distilled water needed
   1-k = fraction of tap water needed to produce
   R = desired resistivity
   r = resistivity of distilled water
   r' = resistivity of tap water, then:

   $k \quad R = \frac{rr' - rR}{r'R - rR}$

   The volume of water required is
   $V' = V\,(1 - k)/k$, V' = volume of tap water required
   V = volume of distilled water required
   Measure R, r, r' with conductivity cell and 1650 A bridge.

   b. Mix thoroughly (about 15-20 min. pumping through recirculating line) until after several samplings no further drift in conductivity is observed.

3. Position water stands, and mount spray heads thereon. Connect hoses to manifold and leave at least two valves open.

4. Start delivery pump after recirculating pump has been shut off and valves repositioned. Run up to show 60-70# gauge pressure with two spray nozzles fully open. Record pressure.

5. Direct spray into catch basin (bucket). Be sure all spray is collected. Time collection rate for 1 minute. Measure volume of water collected and convert to gal/min. Repeat procedure for 4, 6, 8, 10 nozzles at constant pressure, or for 2 nozzles at 80, 90, 100#. In any case collect data and plot parametric in nozzle number the delivery rate as a function of gauage pressure for 5 combinations of nozzles and 4 pressures (20 sets). CAUTION: During this phase of tests, never run pump with all nozzles closed.

6. With pump running at about 70#, all ten nozzles open, close each in turn, observing behavior of pump speed and pressure. Pressure should not show

overshoot, and pump motor should tend to race. Be prepared to throttle down, especially if pressure tends to overshoot. After satisfactory results, retest at 100#, starting with all nozzles open, close all as rapidly as possible, observing pump.

7. Water Spray distribution test: Arrange water towers so that nozzles when active appear to wet an area 15' x 15' when directed approximately 45° down. Place catch basins at center and four in circle about 6' radius. Turn on all 10 nozzles and then start pump, run up to pressure at which a total delivery rate was determined. Holding speed constant, remove covers from catch basins simultaneously and run system until basins have at least one inch of water in them. Measure depth of water, and calculate volume from dimensions of catch basin, taking due account of taper in side walls, if any. Then calculate the delivery rate at each basin in inches per minute by the following formula:

$$\text{Delivery rate} = \frac{\text{volume per unit time}}{\text{catch basin \underline{top} area}} \times \text{cosine } \theta$$

where θ is the plunging angle (estimated) at the top of the catch basin. See figure 2.

Determine the maximum spread of the pattern that hields uniformly of collection over the area sampled of ±25%. The minimum acceptable delivery rate with 10 nozzles operating is 0.2 inch per minute average for each catch basin within the above tolerance.

Using the same pattern as before, cut the number of nozzles in half by shutting off alternate nozzles, and confirm that the delivery rate is halved at the same line pressure and that the distribution remains in proportion and to the above tolerance.

8. Check that communications between test hut, manifold operator, and pump operator are satisfactory.

9. Test of distribution with horizontal spray: Set all nozzles close to bottoms of towers and direct them so that water arrives in horizontal direction over a coverage area of about 10 x 10 feet. Erect and brace a baffle made of 3 4'x 8' sheets of plywood placed vertically as in figure 3. Holes of known size are cut as shown. Hold buckets back of holes, and also build catch trough at bottom of plywood to deliver water to another container. Starting with 10 nozzles as before at a reference pressure, on a signal each person holds bucket to catch water coming through holes.

At conclusion of 1 or 2 minutes, contents of each bucket is measured and divided by area of hole corresponding to it. This gives delivery rate in inches per minute horizontally over area of hole. Do this for each hole, and calculate

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average. Deviation for each hole must be within 25% thereof. Calculate volume of runoff from catch trough, divide this by net area of plywood surface. This should give average rate of non holes and should agree with average of holes.

TEST F-2

Low Level Impedance

1. Establish that induced voltages in coils and capacitor are not a hazard to measurement equipment.

   a. Using high impedance broadband VM: Disconnect capacitor from top of coil 2. Connect VM from top of coil 2 to ground, with helix and variometers connected for maximum inductance. Measure and record voltage. With coil 2 and capacitor still disconnected, connect VM to capacitor.

   b. Repeat A with oscilloscope and high impedance probe of known calibration. Compare results.

   c. Repeat A with 302 wave analyzer and with HF voltmeter.

2. If maximum voltages are safe for instrumentation ratings (decade capacitor, bridge, Q meter) proceed as follows:

   a. Measure capacity of capacitor without HV lead to test object,by 1650 A bridge. Repeat, using Q meter and series capacitor consisting of decade capacitor to keep Q meter on-scale. See figure 4. Compare results and record. They should be within 2%.

3. Set up circuit of figure 4, for resistance and reactance measurement. Power source and decade resistor are inside helix house, with current and voltage indicators; decade capacitor and air capacitor are outside, connected to top of coil 2. Start with maximum inductance in variometers and fixed helix. Make entry of measuring circuitry at top of coupling variometers. Set substitute capacitors to value measured on air capacitor, and connect to top of coil 2. Resonate the series test circuit, using oscilloscope determination of tuned condition. DO NOT EXCEED 130 MA. Record frequency. Disconnect the decade capacitor and place the air capacitor in the circuit. <u>Confirm</u> that the resonant frequency is the <u>same</u> as was measured using the decade capacitor set for the bridged value of the capacitor. If this is <u>not</u> so, repeat the comparison of determinations until agreement is obtained to within 1%.

4. Calculate the change in setting, if any, for fixed helix and variometer that will result in resonant frequency near 28.5 kHz (within 100 Hz). Use the known range of 0.34 - 260 mhy for variometers and 1.75 mhy for full fixed helix for making this estimate, and reconfigure the helix to produce this result.

Repeat step 3, confirm that the apparent capacity of the air capacitor has not changed.

5. With bandwidth resistor in the circuit carry out resistance measurement using ΔR technique. Repeat, using no bandwidth resistor. LIMIT OF CURRENT WITH AIR CAPACITOR IS NOT CRITICAL.

6. Repeat 5 using decade capacitor. LIMIT CURRENT TO 130 MA TO AVOID EXCEEDING 500V LIMIT ON DECADE. Results of foregoing steps yield coil loss, capacitor loss, total circuit loss, coil reactance for 28.5 kHz air capacitor reactance without test object.

7. Bridge test object, and compare with Q meter measurement. Connect T. O. and HV connectors, but leave insulating pad between HV connector and air capacitor. Bridge the combination of T. O. and connector.

8. Estimate further change in helix and variometer setting to tune to 28.5 with T.O., HV connector and air capacitor. Make setting. Repeat steps 4, 5, 6. This establishes circuit impedance excluding coupling variometers. These will add approximately 0.04/21 or about 0.2% to total loop impedance when circuit is normally used, which is an error in test object voltage smaller than the instrumentation error. Note also that this sequence must be repeated for each different test object, although the expected range of variation of capacity is small. Total capacity is approximately 1800 pf, of which test object is about 140 pf down to 50, or +0, -90, or 5%, which is significant.

9. From above results for R&X, determine combiner network settings for best match.

10. Repeat 8, but with only that part of the circuit consisting of variometers and fixed helix inside helix house by connecting decade capacitor to foot of downlead and removing jumper connection from downlead to coil 1. Keep all settings and frequency the same as in step 8, and tune the circuit by adjusting decade capacitor. This procedure gives reactance of helix house only, and thus the voltage ratio between that on the whole circuit to that at the downlead.

TEST F-3
Current Meter Calibration

1. Break connection in series circuit at bandwidth resistor, and insert #10 AWG wire link. Replace air capacitor with decade capacitor and use source to test F-2. Clip Current Probe over short small wire link (see Figure 5). Raise output of amplifier, tune circuit to resonance, and compare circuit probe output with reading of Fluke meter. During this test, record output of HP 302A in test hut as a basis for a linearity test. Use at least 3 levels within range of current probe and rating of decade capacitor.

2. Replace decade capacitor with air capacitor. Starting with highest level used with decade capacitor raise level; observe that 302 and Fluke meter output are linearly related to current probe to limit of probe.

3. Using hipot, compare Jennings meter J1005 readings with hipot. Then connect to top of downlead support insulator. During step 2 above, record Jennings readings, and compare with probe and Fluke readings and 302. Linearity should be observed to within 2%.

4. When range of current probe is exceeded, remove #10 wire connector and probe, and continue comparison to higher levels, to limit of Jennings (90 kV peak or 60 kV rms). This should be to about 70 amperes rms indicated by Fluke. Remove Jennings meter from circuit, continue comparison of HP 302A with Fluke meter readings up to 160 amperes. (NOTE: This test should be done in conjunction with corona detection test to avoid damage to HV circuit).

TEST F-4

Repeat steps 3, 4, of F-3, with J-1005 connected to divider capacitor, J-1003 connected to downlead.

1. Conduct side-by-side comparison of J1003 with J1005 at downlead.

2. Leave J1003 at downlead, place J1005 on divider capacitor (Figure 6) with direct connection to HV bus from divider capacitor. Establish A-B comparison of J1005 with and without direct connection to divider, for same level indicated on J1003 and on all current meter.

3. Working back through calibration factors thus established, confirm that voltage ratio of entire circuit to downlead voltage is as calculated from reactance ratios of step 10 of Test F-3.

4. OPTION: Grading measurements of capacitor station posts. These are carried out using ballgaps set at constant distance across each member of the post in turn. The details are described in reference (c), paragraph 5.

TEST F-5
Carrier Cutoff Checkout

This test consists of 2 parts. The first tests the reliability of the carrier cutoff (CCO) interlocking and switch system. The second tests the effectiveness of a field sensing device to prevent shockloading of the transmitter during flashover tests.

1. Close all gates and place all switches (panic switch, CCO manual, override and CCO deadman) in "transmitter operate" position. Monitor the CCO system while each switch is opened in turn to establish that the CCO system is activated. This step is carried out with transmitter inactive machine.

2. Repeat with transmitter active at low to moderate level (not over 30 amperes) to assure that the interlock system is indeed effective.

3. Set up the Westinghouse CCO box that is used with the Westinghouse rod gap in a convenient location and connect its output into the CCO systems. Locate the two capacity sensors in a manner similar to that used at one of the antenna towers, placing the general field sensor at a relatively remote location such as near the equipment access gate. The local field sensor for purposes of testing is located near the downlead protective ballgap. The gap is set for a moderate voltage, such as not to exceed 50 kV, or about 13 amperes in the circuit. By successive adjustment of the size of the sensing capacitors and the bridge circuit balance the device is set to cause carrier interruption if possible immediately following an arc but not so near its occurrence as to prevent it; at the same time the circuit should cut the carrier before the shock pulsewave from the arc is propogated back through the helix and matching circuit to cause possible horngap arcs and breaker trips.

After these low level tests have been conducted satisfactorily, and after corona detection and heat rise tests have been run on the test circuit, the CCO system tests are run at higher levels, at first without test object and high voltage connector, using a location near the high voltage ballgaps for the local field sensor. The gap itself is set to arc over at intermediate levels near 300 kV or 115 amp in the circuit.

After the test object is in place, the system is checked again. The local field sensor is placed near the test object at a location similar to that which will be used operationally at one of the antenna tower bases.

TEST F-6

Corona Detection

intended to assure that the circuit is corona free and has no ıy destructive hot spots.

.ne circuit operation is started at a moderate level, 100 kV (approximately ɹ amperes) and slowly brought to full voltage. The increase in level is accomplished incrementally and between each increment the circuit components are checked manually for excessive temperature rise. Voltage increments are 50 kV, and the period of time for a run is 10 minutes.

The procedure is:

1. Bring transmitter up to starting level, 100 kV, in about 2 or 3 minutes, while observing circuit for corona. If no problems are evident, run at that level for 10 minutes. Shut down transmitter, and immediately check for hot spots. If none are found, bring up transmitter to previous level first, then over a period of one or two minutes, raise voltage to next operating level, in this case 150 kV. Repeat the 10 minutes run if no corona is evident. If corona is observed, immediately stop the procedure and apply a fix. Retest at the level at which corona was observed before proceeding to higher levels. The same remark applies to hot spots.

Proceed in this manner until full 500 kV operation is attained or whatever lower limit is possible. The minimum acceptable level is 300 kV.

The following observation points will be manned. Note that this test is the only one for which personnel will be inside the boundary fence and outside the test hut. They will use polypropelene rope tethers (safety lines) which are to be anchored to some fixed object and to belts worn by the individuals to prevent wandering around the area.

a: Top of ladder overlooking helix house roof.

b. Halfway between test hut and equipment gate, looking at downlead and coils.

c. Same, but looking at capacitor.

d. Northwest corner of fence, looking at capacitor.

e. Southwest corner of fence, looking at capacitor.

f. Halfway from southwest corner of fence to test object location, <u>outside</u> fence.

server position, looking at coil, capacitor, downlead.

rence, at angle between berm and helix house, looking at downlead.

ide test hut.

observer will be equipped with 7 x 50 field glasses. They will sweep their signed areas primarily, but should not ignore others.

Particular locations for attention are:

a. All hardware connections and mounts on helix house roof, including 90° elbow and 45° elbow bends and insulator hardware.

b. Downlead hardware details, top and bottom turns of coil 1, bottom turn of coil 2, especially around gap and bolted fittings in lexan supports, coil corners.

c. Capacitor grading rings and support struts viewed from east. Also, flat plate braces between doubled longitudinals.

d. Same, other side (viewed from west).

e. Same, viewed from southwest, also general view of downlead.

f. Same as 5, also top connector of coil 2.*

g. Top turn coil 2, coil corners and bottom edge of vertical section supporting coil end of HV connector to capacitor.

h. Downlead fittings, bottom turn of coil 1, especially bolt heads on connectors and litz at end of turn 1 and start of turn 2. Also, water towers.

i. Such areas as are visible, ballgaps at dl and hi V bus.

Note that these locations are assigned to the positions noted previously.

In the event any problem is noticed, the observer making the observation calls to the safety observer to shut down the transmitter. If need be, the observation will be confirmed by repeating the test, coming up to observation voltage level by a slow rise from a level known to be safe. The fix will be applied if the full 50 kV increment has not been made, and the latter accomplished, before making a ten minute heat run at that level.

The entire assembly of coils and the top portion of the downlead accessible from the helix house roof are the areas checked in the heat runs. The items of particular interest are the following:

*litz pigtail and bolt heads

a. Elbow bends at the 45° and 90° locations.

b. Two-inch diameter connector from downlead to bottom turn of coil 1.

c. All 45° angle bends in bottom turn of coil 1.

d. The 6" shielded flex tubing top corona ring, coil 1, and bolts.

e. Flex tube connector, coil 1 to coil 2.

f. Bottom 6" shielded flex tubing bottom corona ring, coil 2, and hold 1 down bolts.

g. Top 8" shielded flex tube top ring coil 2, connectors, and hold down bolts.

h. All cemented joints on coils and PVC braces.

Each suspect location will be checked manually for temperature rise. If any are found, a judgement by the Test Director will be made as to safety of preceeding to next higher level. When a situation is reached that the temperature is considered dangerous, a fix will be devized before proceeding to next higher increment. If none can be applied, this condition will be considered to limit the circuit. Goal is 500 kV, with 300 kV minimum.

TEST F-7
Gap Calibration, Heat Run

ɡeneral procedure is similar to that used to calibrate all gaps, in-.g test object gaps. Initial settings are based on the assumption that - gap flashovers are roughly ten kilovolts per inch for dry conditions, and 0.6 the value for wet.

Large gap will be calibrated first. The gap is presently set for its minimum separation, 20 inches between opposing surfaces, slant distance. Bring up circuit on 28.5 kHz to approximately 150 kV. Then conduct a flashover test using the procedure of references (e) and (f), under dry conditions. Change gap setting to a larger value, estimating new gap by projecting to a voltage higher than the first by 15% of the difference between it and the 500 kV circuit limit. Continue in this manner, until gap has been set for a voltage equal to the circuit design limit. Recheck this setting under both wet and dry conditions. Reset the gap to a separation calculated to correspond to a value, wet, midway between the wet flashover opening and the dry flashover opening to the circuit design limits.

Small gap (downlead) is calibrated in the same fashion, starting at a setting calculated to be in the same ratio as the voltage division determined in Test F-4, using an absolute value of not over 50 kV to start (50 kV at the downlead). Proceed as in large gap setting, objective is to get the two gaps to fire simultaneously.

After setting both gaps, run circuit for 20 minutes at design limit, and check for hot spots as in Test F-6. If this is satisfactory, run for 40 minutes. Finish by a continuous run of one hour.

As an option, mount a pair of rough brass spheres and run calibration checks wet and dry vs separation. Compare these results for 6" spheres with the 3" graphite and the 18" aluminum spheres.

TEST F-8

Final CCO Setting

This test is run in a manner similar to F-5, but with test object in position and the local field sensor near the test object. It will be necessary to set the imbalance detector circuitry to a condition near that expected in test object flashover measurements. It is not known at the time of writing of these test plans if this is a practicable procedure.

TEST F-9

Test F-9 is a demonstration of WFO, DFO, WCI, DCI using test objects of various configurations on the small pad. The test object will be provided with removable corona rings so that A-B tests with and without anti-corona hardware can be shown. The test object will be composed of:

1. Single NELC 31" station post.
2. Dual NELC 31" station post.
3. Triple NELC 31" station post.
4. Single stick insulator.
5. Tripod assembly of sticks.
6. Brass sphere gaps.

1 through 5 above can be conducted with and without anti-corona hardware.

Prior to actual testing a brief lecture and slideshow will be presented in the NRTF theater to give background on the program including present insulator problem, previous test sequences and results, present circuit design concepts and capabilities, and results expected from insulators under contract.

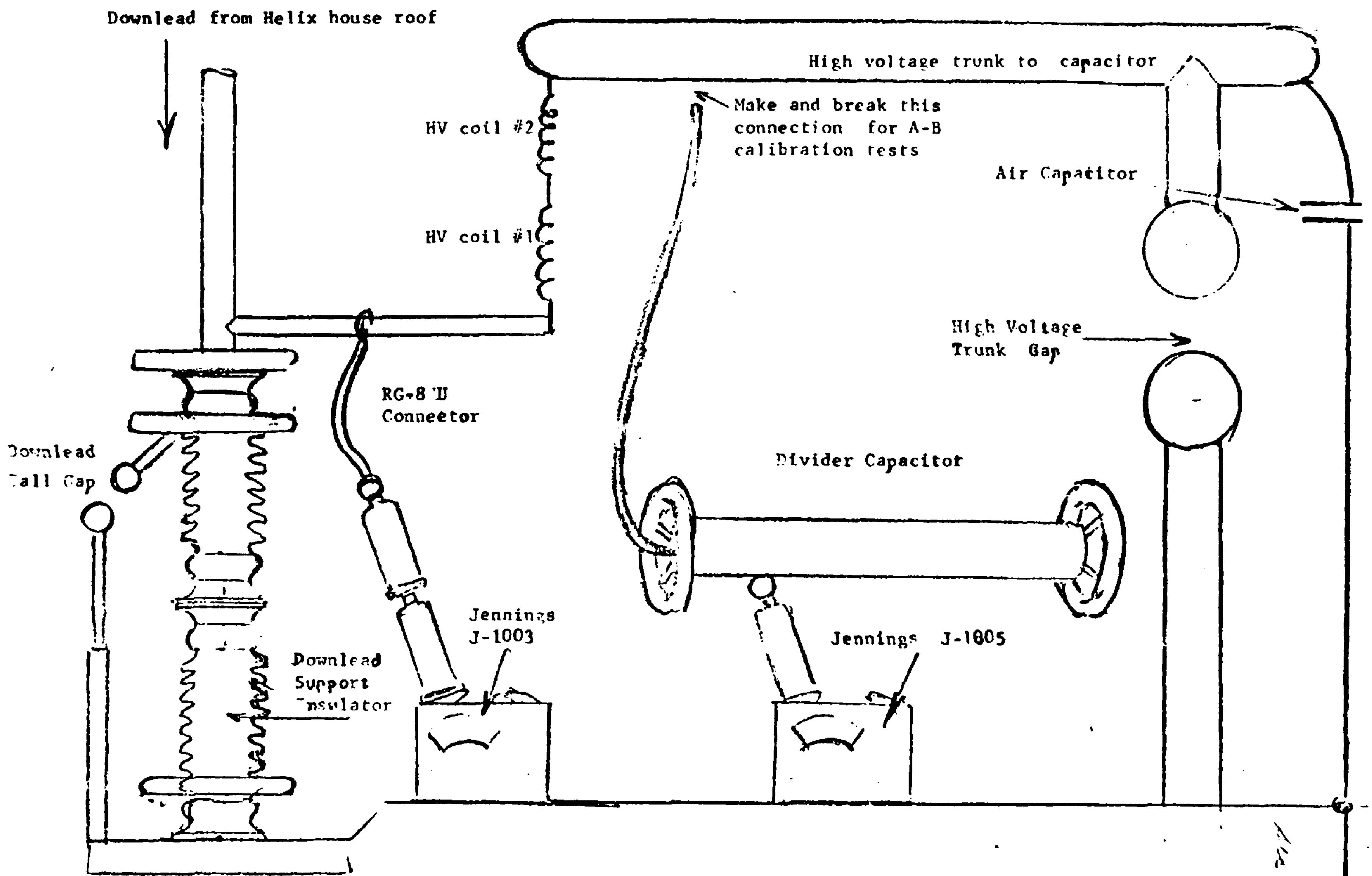


FIGURE 6: CIRCUIT FOR COMPARING VOLTAGE IN EXTERNAL CIRCUIT WITH LEVELS CALCULATED FROM CURRENT IN CIRCUIT AND MEASURED REACTANCE, AND DETERMINATION OF VOLTAGE RISE IN THE COILS

NELC 10/29/73

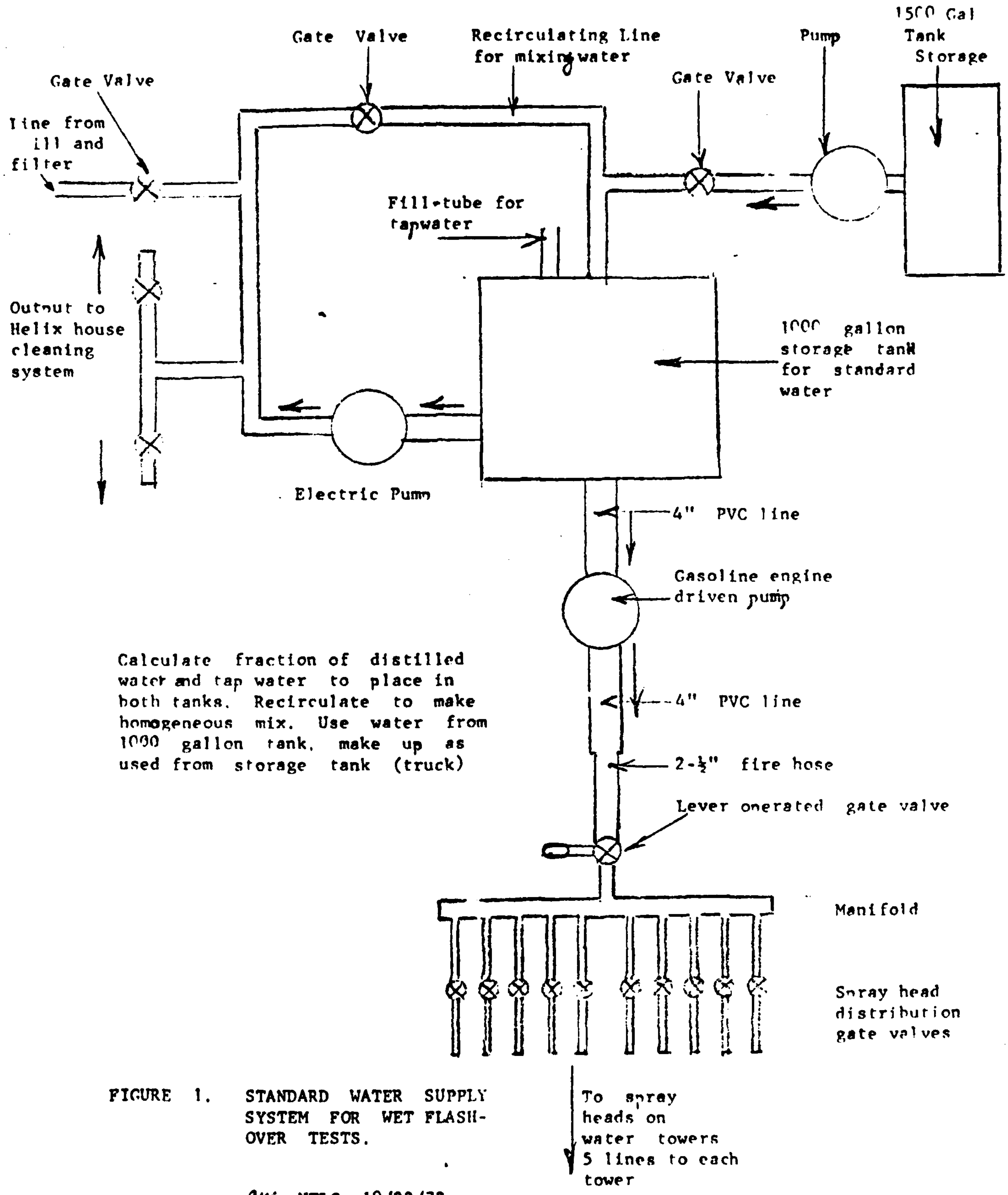
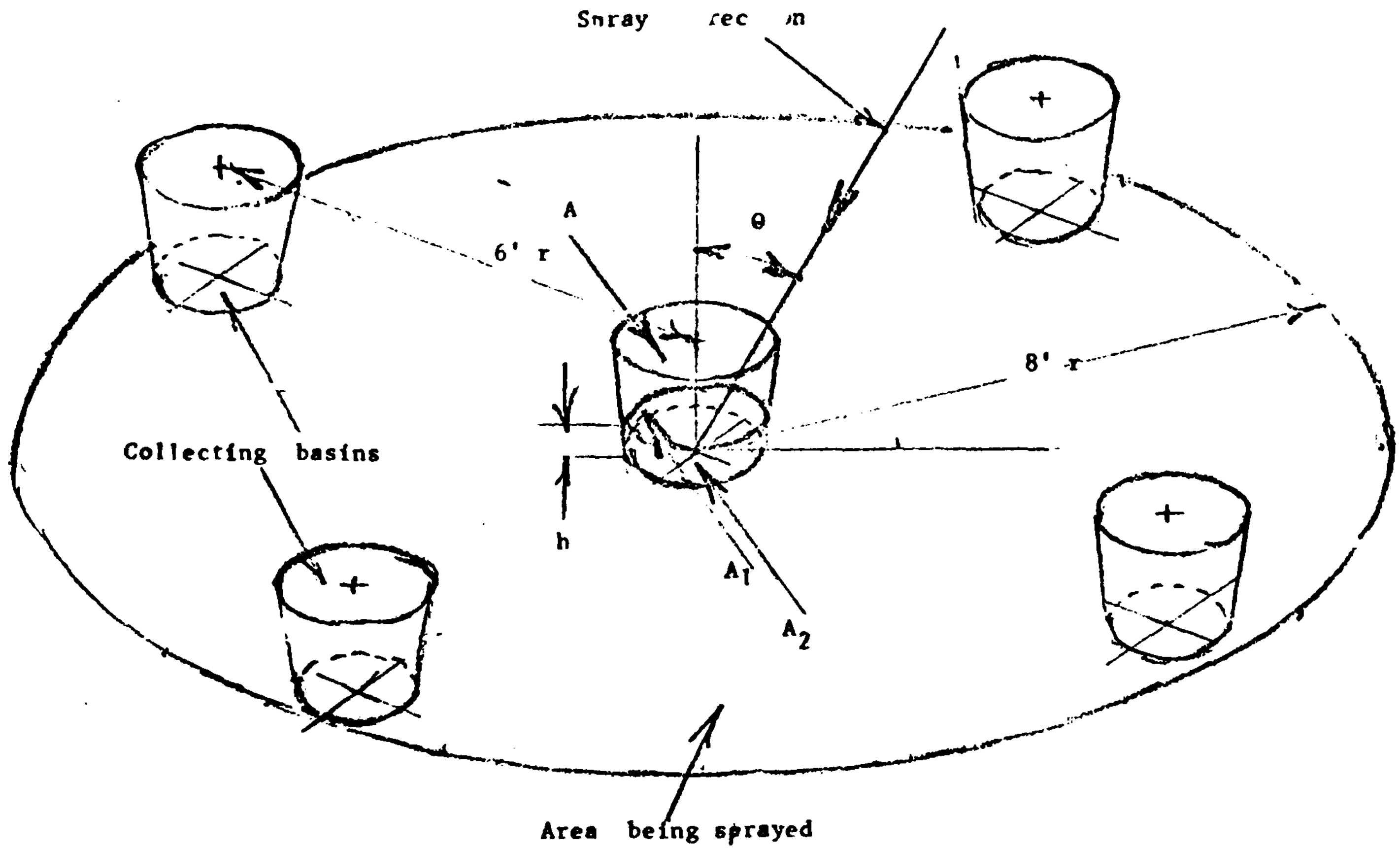


FIGURE 1. STANDARD WATER SUPPLY SYSTEM FOR WET FLASH-OVER TESTS.

ays NELC 10/23/73



Delivery rate into catch basins:

$$D = \tfrac{1}{2}(h/A)(A_1 + A_2)\frac{\cos\theta}{T}$$

All dimensions inches. Delivery rate will be in inches per minute

Calculate for each of the catch basins the individual delivery rates and then take the average Individual deviation shall be no more than 25% from the average

A = area of open top of catch basin

A_1 = area of top surface of water collectd

A_2 = area of bolttom surface of water collected

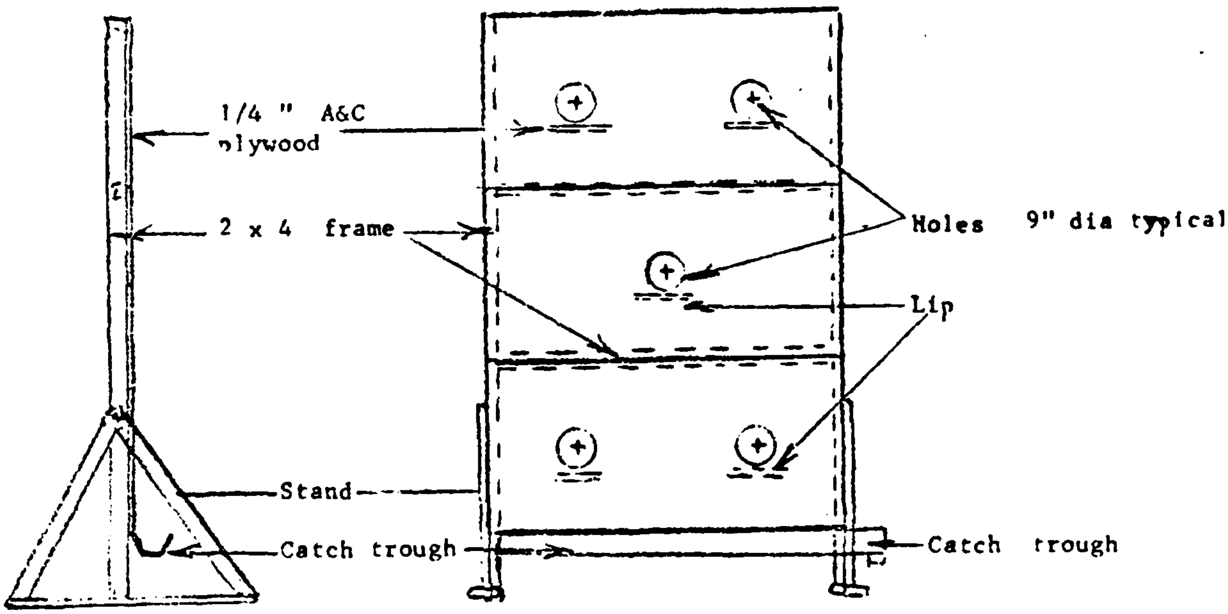
h = depth of wate in catch basin

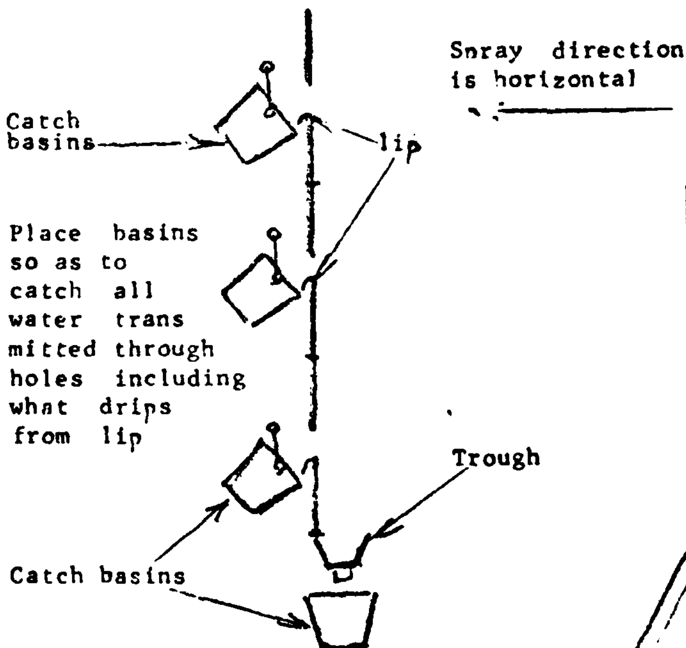
θ = plunge angle of water (measured from vertical)

T = time in minutes

FIGURE 2: MEASUREMENT OF SPRAY DELIVERY RATE

drs NEIC 10/23/73





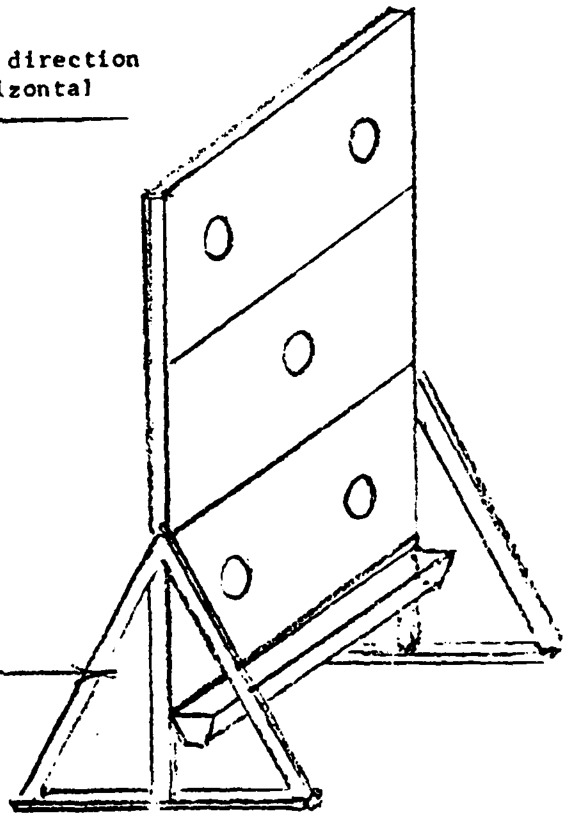


FIGURE 3: BAFFLE FOR MEASUREING HORIZONTAL SPRAY DELIVERY RATE

NELC 10/23/73

Note: Calculation is made as in Fig 2 except Cos θ = 1

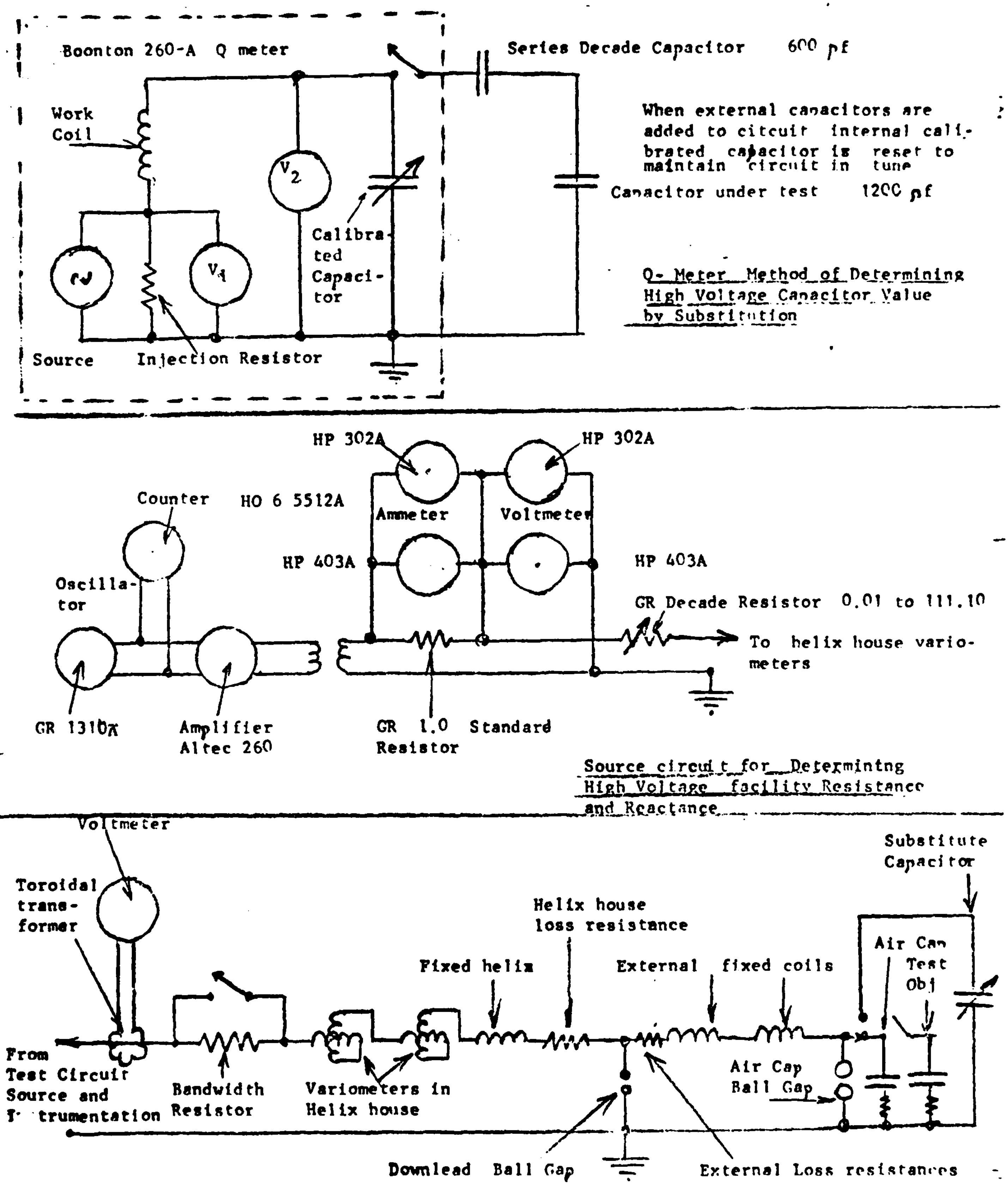


FIGURE 4: CIRCUITS FOR MEASURING HIGH VOLTAGE CIRCUIT PARAMTERS

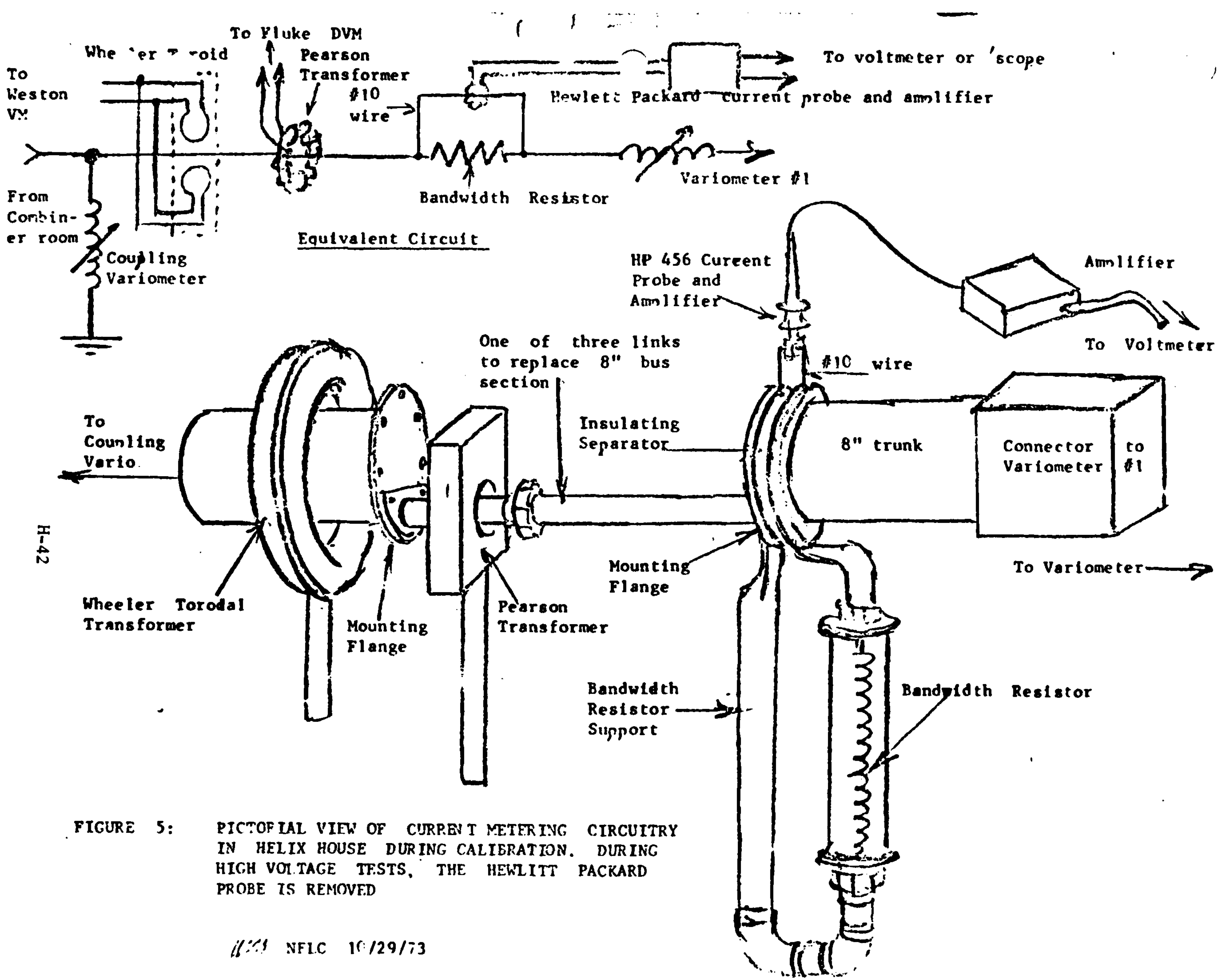


FIGURE 5: PICTORIAL VIEW OF CURRENT METERING CIRCUITRY IN HELIX HOUSE DURING CALIBRATION. DURING HIGH VOLTAGE TESTS, THE HEWLITT PACKARD PROBE IS REMOVED

NFLC 10/29/73

S/N 0107-778-6099
DEPARTMENT OF THE NAVY

Memorandum

DATE: 29 April 1974

FROM A. N. Smith, U. S. Navy Electronics Lab Ctr. ANS

TO W. E. Norris, NAVELECSYSCOM HQ, PME 117-223

SUBJ Supplemetary Mockup Test Plan and Schedule

Dist: CEMCO (2)
NAVELX PME 117
0510
NELC 1300
2100
2160
NRTF L01
L05
NAVSEEACTPAC
NAVFACCHESDIV
NBS (Dr Ketter)
Wash Dur
NavFac HQ PC6
- NavFac Pac Div (George)

Ref: (a) Phonecon 4/29/74 ANSmith/W. E. Becker, NAVELEX
(b) NAVCOMMSTA HONO 022001Z April 74

Encl (1) Test Schedule dtd 4/25/74
(2) Mockup Test Sequence

1. Encl (1) and (2) are supplied herewith in accordance with ref (a) and also discussions with the undersigned CEMCO representative. Encl (1) is a revised schedule and replaces that of ref (b) due to delay in arrival onsite of mockup hardware for testing from 17 April to 23 April 74.

2. It understood that the tests listed in Encl (2) are based on general information and guidance given by the Contractor, Continental Electronics Manufacturing Co, under contract N00039-74-C-0052, and that Encl (2) was arrived at by mutual agreement between the Navy Test Director and the Continental representative prior to start of testing on 4/25/74. They are to be run as developmental tests on protective gap hardware (Phase 1), on mockup rainshield hardware (Phase 2), Tests on generalized protective system hardware, as yet undefined to serve as guidance if desired for the Contractor's future effort(Ph 3 are scheduled as shown by agreement, but content is to be determined by Test Director, and presently is not CEMCO responsibility.

3. It is further understood and agreed that at the conclusion of the tests listed in Encl (2) further development tests may be found desirable on both gaps and rainshield hardware, and that these may be scheduled as convenient any time in the test sequence. Dates called out in Encl (1) are therefore regarded as flexible, except that a prior existing committment by NAVFACENGCOMPACDIV for installing furhter modifications to the helix house require an end date for electrical tests of 5/29/74. After this date no further VLR tests will be possible until 15 July, 1974.

4. It is also understood and agreed that neither Encls (1) and (2) nor furhter tests per paras (2) and (3) above not described as yet, nor changes in indicated completion dates, constitute in any way direction of the Contractor under N00039-74-C-0052, or change orders thereto. Likewise test results officially reported to NAVELEX by message by the Test Director shall not constitute direction of the Contractor, but no test results not reported by message shall be regarded as official representations by the Navy.

Andrew Nowell Smith
Andrew Nowell Smith
VLF Facility Test Director

Conover Hartin III
Conover Hartin III
Continental Electronics Re

Encl (2)

PROPOSED CEMCO BIA MOCKUP
DEVELOPMENT TESTS 4/24/74 - 5/24/74

1. Intratier Gap system, using several combinations of settings for upper and lower gaps, mounted on original mockup hardware configured as for tests conducted 1/14/74 through 1/24/74 with additional 3" torus placed under top plate of lower insulator tier outboard of insulators.

Lower gap consists of 6" dia sphere on 2" dia rod. Upper gap consists of 2" dia rod with hemispherical cap same diameter. Clamps are improvised to slip into space between center mockup insulator mounting plates

1. Calibrate top gap, bottom shorted DFO, DWS
2. " bottom " top " " "
3. Both gaps active, set top to approx 150, bottom to 170, or whatever setting makes top gap arc first, with bottom gap controlling location of arc path, resultant DFO to be greaterthan 450 kV
4. Repeat 1. wet
5. Repeat 2 wet
6. Repeat 3 wet (both gaps). Resultant WFO greater than 375 kV
   WWS " " 300 kCV
7. Repeat 3 and 6 for corona incepteion/extinction Wet level unspec
   Dry " gr. th. 285 kV
8. Check test circuit calibration
   a. Whole BIA
   b. Two halves separately
   c. Whole BIA with flex tube trunk replacing standard (option)

2. Remove gapps. Check mockup hardware and compare with January results for
   DFO
   DWS
   WFO
   WWS

3. Add to existing mockup hardware an 8" thick torus extension ring on brackets supplied by CEMCO located anular to top rain shield with 12 inch spacing between outer surfaces (see sketch #1). Relative vertical location of under surface as follows:

1. -3 inches
2. 0 "
3. +4 "
4. +7-3/4 "
5. +10 "

In each case determine WFO and WWS. In cases 1 and 4 determine grading using sphere-gap voltmeter technique, flashing each gap in turn, with the other present but spaced too far to flash.

4. Set 8 inch torus as in 3-4 above, and add a 6 inch torus anularly with rainshield and 8 inch torus, spaced 6 inches between outer surfaces (sketch 2). Relative vertical location of under surface of 6 inch torus as follows, referred to 8 inch torus:

1. +3 inches
2. +6 "
3. +12 "

4. Other, either with 6 Inch horizontal spacing, or other combination as experience indicates

Check grading of BIA in atl east one configuration in this set, and also test facility calibration if this appears desirable.

5, Return to only that hardware described in section 1, above, but without gaps, and with top rainshield inverted as for some of the tests performed in January of 1974. Under surface of inverted rain shield is flush with top surface of B IA top insulator mounting plate, and sealed with RTV. Mount bracket supporting 8 inch thick torus on staging contained within the bowl formed by inverted rain shield so as to permit attaining vertical relationships called out below. Refer to sketch 3 for definitions: Test for WFO, WWS; check grading for at least one.

1. 0 inches
2. 4 "

6. With hardware as described in 5 above, add second 6 inch thick toroidal anulus, with horizontal spacing between outer faces of toroids 8 or 12 inches (it may be necessary to try both). Test for WFO, WWS. Check grading for one combination. Distances are vertical separation of under sides of torieds (sketch 4).

1. 0 inches
2. 4 " (also others as time and experience indicate)

7. Replace original top rainshield with new ochagonal rainshield mockup.

1. Repeat WFO and WWS tests run 20 March 74, and check grading with rainshield upright.
2. Remove wide, flat rainsheild at bottom of upper tier, replace with 3" thick anti corona ring taken from under top circular rain shield on lower tier (see sketch 5). Retest for WFO, WWS and grading.
3. Geometry as in 2, but with octagonal rain shield inverted
4. Return center hardware to condition as in 1, keep top octagonal rainshield inverted
5. Using either 3 or 4, whichever is better, add external 8 inch thick annulus, as in Section 3.

In 3, 4, and 5, WWS and WBO and grading are to be measured, and facility calibration determined in at least one instance.

8. Return hardware to configuration of Section 7-1, except without either original or octagonal rainshield. Place 6 inch thick torus outboard of sharp edge of upper plate of top tier. Place 12 inch thick torus outboard of this on struts mounted to center (between tier) hardware soa as to provide shiled as in Mod 21 of three tier Isolation Unit. Measure DFO, DWS, WFO, WWS and grading, as well as facility calibration. Also strut-type top grading ring mounted from spider on top plate, no rainshield

9. Return BIA mockup to either original (section 2) configuration or to optimum configuration of Sections 3 through 8. Assemble protective gap devices as advised by NBS representative, and test for all calibration conditions required by I-157, and others at option of Government representatives.

Item 1. Serves as development tests on Contractor-provided protective gap hardware, or Phase 1 tests. Sections 2 through 7 serve as development tests of Contractor-provided rainsheild mockup modifications, or Phase 2 tests. Section 9 serves as generalized protective system hardware tests for Contractor guidence, or Phase 3 tests.

DEPARTMENT OF THE NAVY
Memorandum

DATE 9 May, 1974

FROM A. . . Smith, NELC Code 2160 *AUS*

TO . . Morris, NAVELECSYSCOM PME 117-223

SUBJ Mockup Test Configuration

Dist: CEMCO
NAVELEX
PME 117
0510
NELC
1300
2100
2160
NRTF LLL
L01
L05
NAVSHEACTFAC
NAVFACHQ PC6
NAVFACCHESDIV
NAVFACPACDIV
NAVELEXWASHDIV
NBS

Ref: (a) NS memo dtd 29 April 1974

Encl: (1) Figs 1 thru 5, BIA Mockup

1. Encl (1) shows configurations of CEMCO BIA mockup hardware tested in the period 25 April - 8 May 1974 at the NELC Lualualei VLF test facility. Some dimensions called out for test in Ref (a) were changed, and some configurations were omitted.

2. By mutual agreement between the Test Director and the CEMCO representative, and without direction of the contractor, tests with the octagonal rainshield were dropped from the sequence (item 7, Ref (a) Encl (2).

3. Several configurations appear to have met requirements of NAVELEX Spec I-157. Numerical results will be reported by message following this memo, and will refer to the figures enclosed herewith for description.

4. No gap system tested to date in the present test series will satisfy I-157, and a protective system configuration is thus as yet undetermined.

5. Gap system development tests and fundamental studies planned by Dr. F. A. Kotter of NBS were started 5/7/74, and will continue until end of scheduled period per Incl (1) of ref (a).

STANDARD CONFIG. CEMCO BIA MOCKUP as tested at A.B. Chance 12/10-14/73 and LLL 1/15-16/74, 1/23/74

Test Series 1, 2, and Generalized Gap Tests

B, G, I, O: 2" Plates
A: top rainshield
E: upper centre r.s.
F: Lower " "
C, D, H, J, K, L, M, N: corona rings

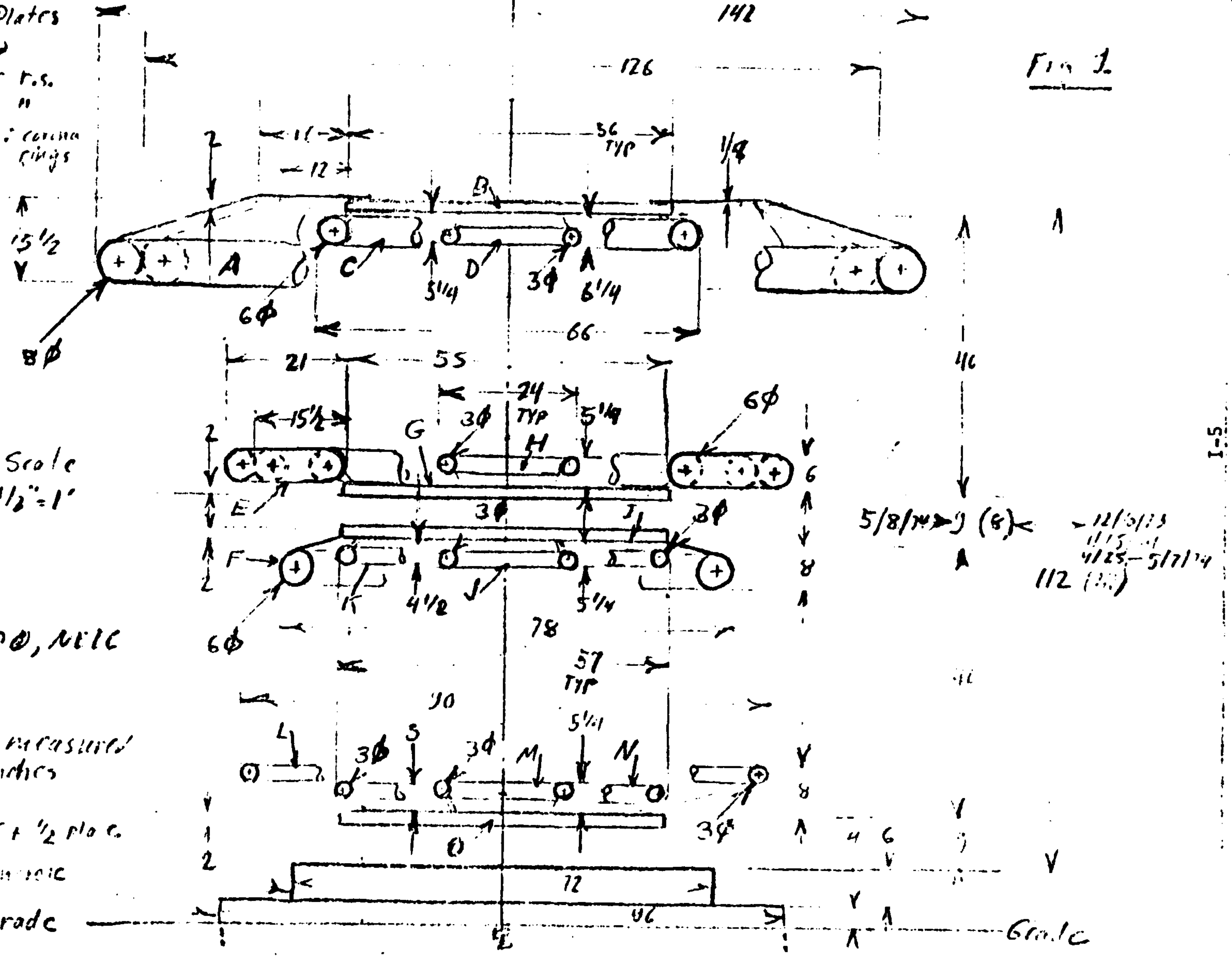


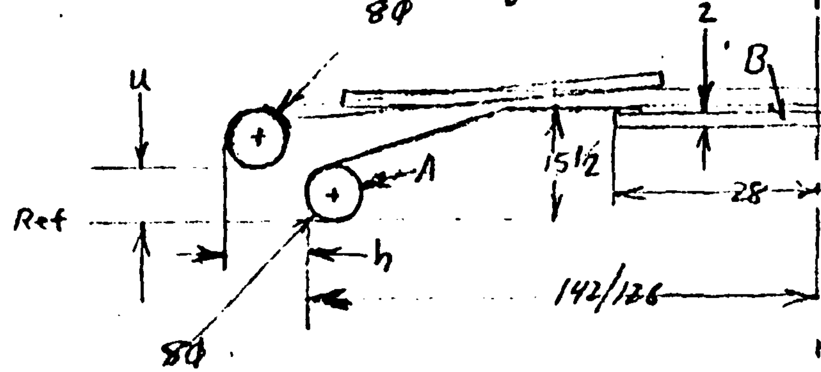
Fig. 1

Scale 1/2" = 1'

Dimensions as measured in field, inches

Grade

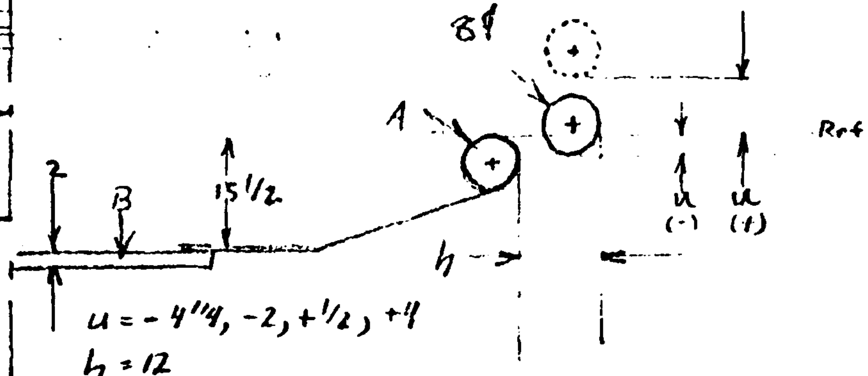
Test series 3: 1 extension ring, top r.s. upright



$u = -3, 0, +4, +7\frac{3}{4}, +10$

$h = 12$ All other hardware standard

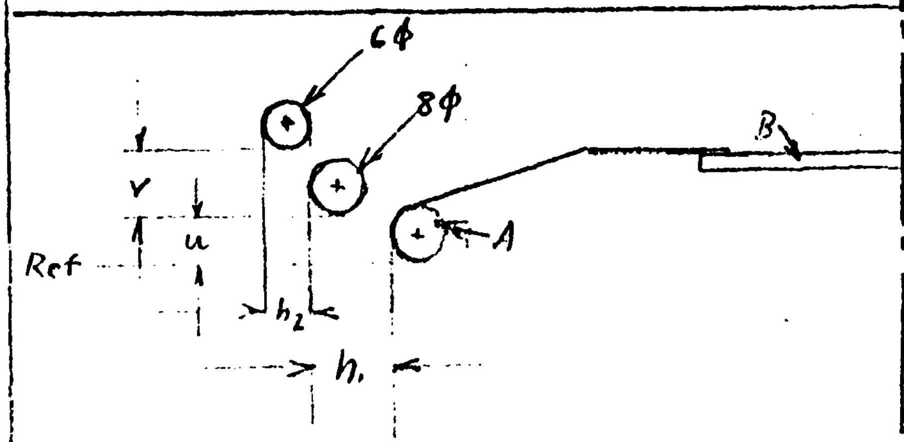
Test series 5: 1 extension ring, top r.s. inverted



$u = -4\frac{1}{4}, -2, +\frac{1}{2}, +4$

$h = 12$

All other hardware standard



Test Series 4: 2 extension rings, top r.s. upright

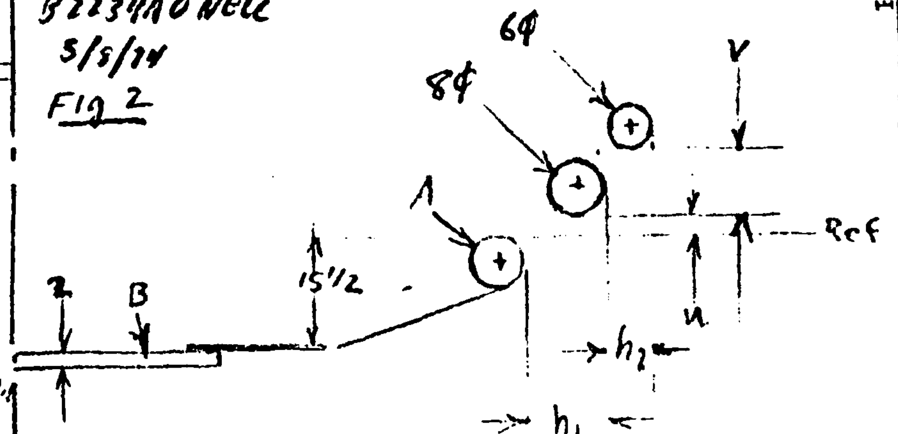
$h_1 = 12$ All other hardware standard

$u = 7\frac{3}{4}$

$h_2 = 6$

$v = 3\frac{1}{2}, 6, 12$

AHS
B2234A0 NELL
5/8/74
Fig 2



Test series 6: 2 extension rings, top r.s. inverted

$h_1 = 12$ All other hardware standard

$u = 2\frac{3}{8}$

$h_2 = 6$ $v = 9$

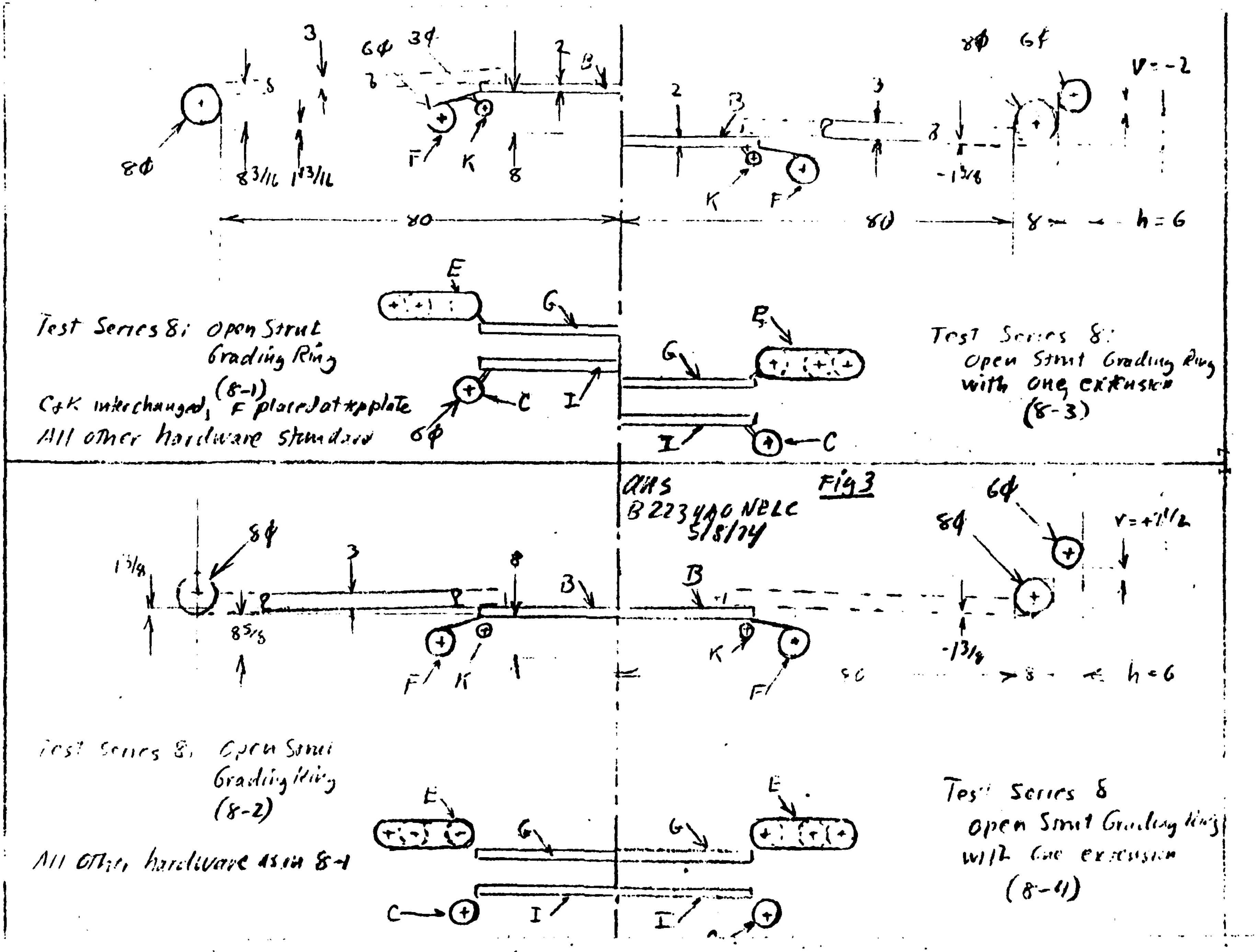
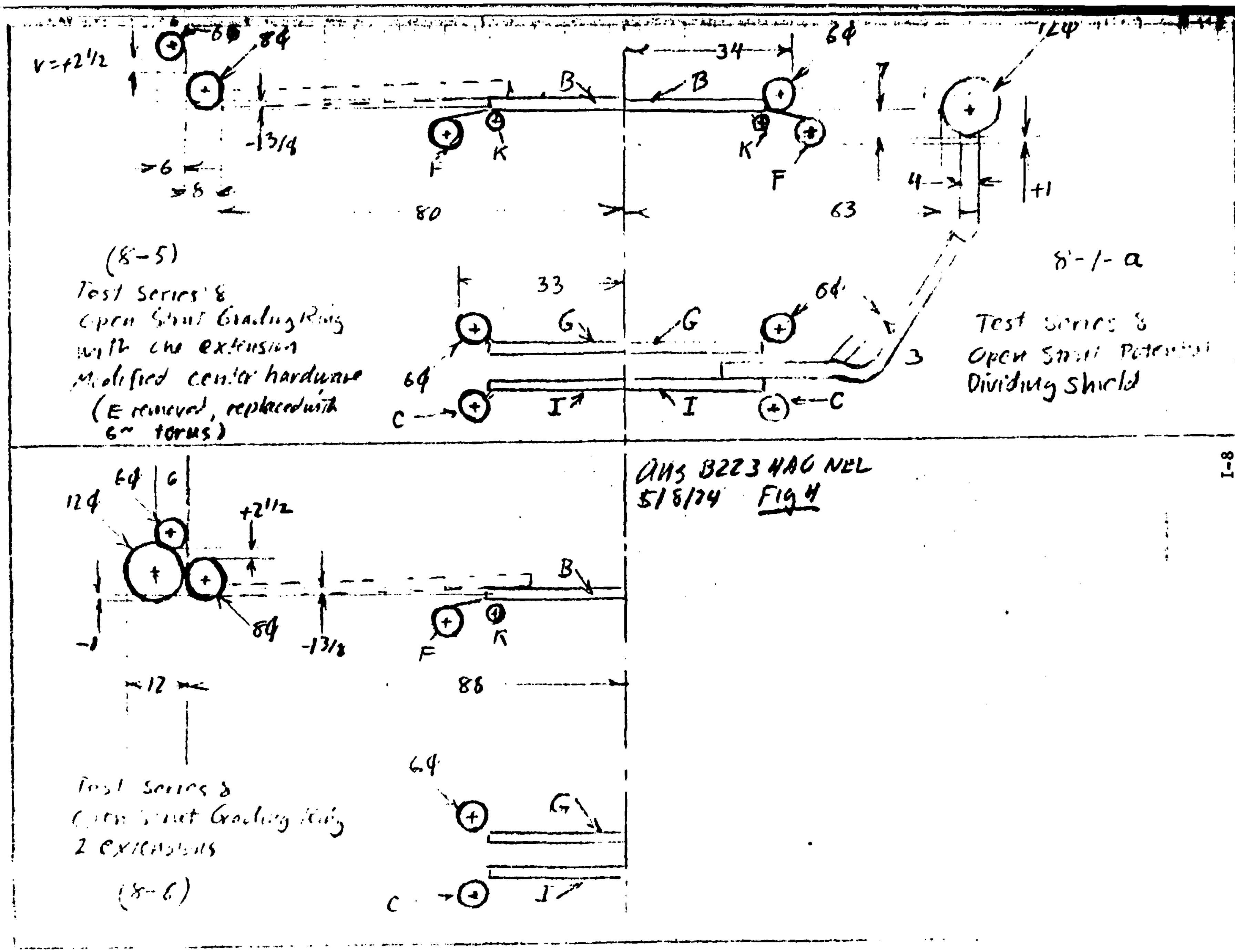
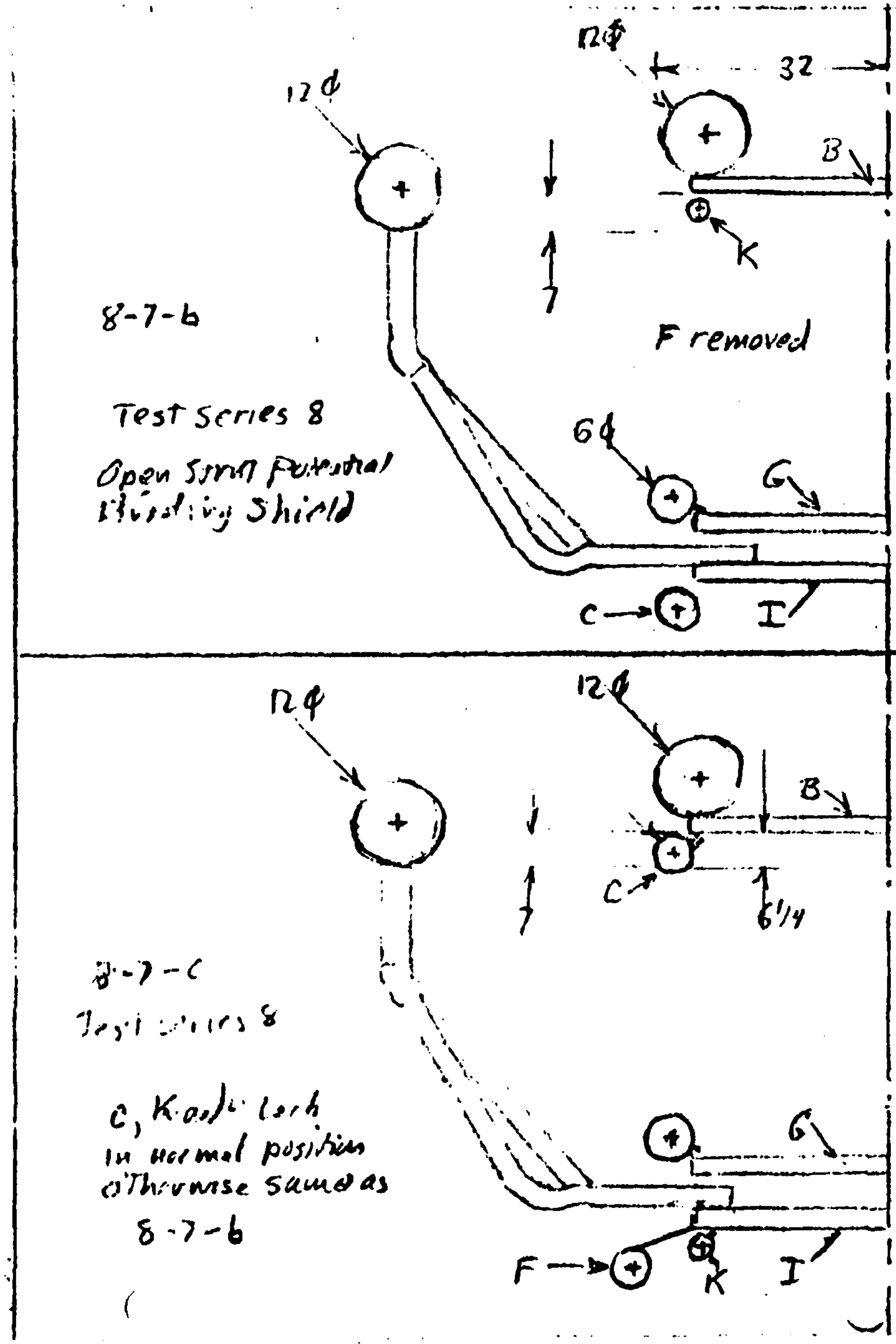

Test Series 8: Open Strut Grading Ring (8-1)
C & K interchanged, F placed at top plate
All other hardware standard
Test Series 8: Open Strut Grading Ring with one extension (8-3)
Test Series 8: Open Strut Grading Ring (8-2)
All other hardware as in 8-1
Test Series 8 Open Strut Grading Ring with one extension (8-4)
AHS
B223420 NELC
5/8/74
8Φ
6Φ
3Φ
80
h = 6
V = -2
V = +1½
8 3/16
1 13/16
-1 3/8
8 5/8
B
E
F
G
I
K
C

Fig 3



(8-5)
Test Series 8
Open Shut Grading Ring
with one extension
Modified center hardware
(E removed, replaced with 6" torus)
8-1-a
Test Series 8
Open Shut Potential
Dividing Shield
Test Series 8
Open Shut Grading Ring
2 extensions
(8-6)
AHS B223 HAG NEL
5/8/74 Fig 4



ANS 3223480 NELC
5/8/74 Fig 5

OPNAV 5216/145 (Rev. 3-71)
SN-0107-778-9110

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~~Ser 2100-122~~

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2. Both addresses must be appropriate for window envelope or bulk mailing, as intended. Include attention codes, when known. Use dots and brackets as guides for window envelope addresses.
3. Give priority to processing, routing, and action required. Avoid time-consuming controls.
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To:
Commanding Officer (CHESDIV FP02)
Chesapeake Division
Naval Facilities Engineering Command
Building 57
Washington Navy Yard
Washington, D. C. 20374

STANDARD REFERENCES AND ENCLOSURES, IF ANY, TEXT AND SIGNATURE BLOCK

Subj: Static Isolation Transformer, Detailed VLF Test Plan

Ref: (a) NELC ltr ser 2100-86 of 30 May 1975
(b) NELC ltr ser 2100-120 of 25 Sep 1975
(c) CHESNAVFACENGCOM 041757Z AUG 75
(d) CHESNAVFACENGCOM 051759Z SEP 75
(e) NELC SAN DIEGO CA 081712Z SEP 75
(f) NELC ltr B228 ROE:em ser 1300-643 of 26 Sep 1975

Enclosure (1) is herewith forwarded for your information and retention. It is intended that taken together with references (a) and (b), the three documents constitute a complete detailed test plan and milestone book for carrying out VLF acceptance tests on the first delivered item under CHESDIV contract N62477-75-C-0043. When the data sheets supplied herewith are properly filled in and signed off by the cognizant authorities, they and the book constitute the final report by NELC on acceptance tests of this isolation unit.

The present document is the final submission in response to references (c) and (d). It is as complete and detailed as is possible in the time frame allowed for its composition.

Although not of itself contractually a cause for rejection of the unit, the presence of corona inside the device may be a detriment, and provision has been made in the plans to use oil samples drawn in closed syringes as controls, when properly analyzed, on the possible change of the condition of the oil as a result of the test program. It is especially recommended that the long term, 144 hour

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Naval Electronics Laboratory Center
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NELC B228
ANS:rdl
Ser 2100-122

heat run, test be implemented so as to get the most operating time practicable during the test period. Experience has shown, reference (e), that changes if any due to corona will be evident in such a time frame. Reference (f) documents some of the investigation carried on at NELC on diagnostic techniques being developed. To date, the only known available commercial technique of value is that developed and available on a regular basis from Doble Engineering, Inc. It is strongly recommended that the oil testing be implemented by CHESDIV.

In view of the proximity of starting scheduled tests, it is recommended that any changes, deletions, additions, etc., desired by CHESDIV, to this test plan be communicated by message to the addressees in the distribution list.

Charles A. Nelson

CHARLES A. NELSON
By direction

Encl:
(1) Static Isolation Unit VLF Test Plan, Annex for Detailed Test Procedures and Data Sheets

Copy to:
NAVELEX PME-117
NAVELEX 51012
NAVFAC HQ PC-6
NAVSEEACT PAC 210 GU
CIVENGRLAB Port Hueneme
NAVCOMMSTA HONO (NRTF LLL VLF Officer)
PACNAVFACENGCOM 09A23C
2100 (2)
2130
2000
2020
2040
1300
6460 (4) (w/o encl)

Prepared by: Andrew N. Smith, Code 2100, X7303
Typed by: Roberta Lanning, Code 2100, 29 Sep 1975

STATIC ISOLATION UNIT VLF TEST PLAN

ANNEX FOR DETAILED TEST PROCEDURES AND DATA SHEETS

30 Sept 1975

1. GENERAL DESCRIPTION

1.1 VLF electrical testing is a requirement for acceptance of the Static Isolation Unit under Contract N62477-75-C-0043 issued by Chesapeak Division, Naval Facilities Engineering Command, and ammended by Mod P00001, Navfac Spec 21-75-0043 25 March 1975. These requirements are called out specifically in Section 3 Materials and Equipment paragraphs 3.8.6.1 VLF Wet Flashover (modified by P00001 Para 6); 3.8.6.2 VLF Dry Flashover; 3.8.6.3 VLF Dry Corona; 3.8.6.4 VLF Wet Corona (Modified by P00001 Para 7, adding VLF Wet Withstand); P00001 Para 8 adding new para 3.8.6.7 VLF Voltage gradient; the requirements actually to test for these items are contained in Section 4 Testing paragraph 4.2 VLF Testing.

1.2 The VLF testing will be carried out at the NELC VLF Test Facility at NRTF Lualualei, Oahu, Hawaii. This facility is capable of delivering 550 kV under spray wet conditions on the test piece for extended periods of time for withstand, corona inception, or flashover tests. It requires the use of the FRT 64 VLF transmitter, in a linear mode of operation, as a source of power. All VLF tests will be carried out at the U. S. Navy's assigned test frequency of 28.5 kHz. Since this frequency is near the upper limit of the specified VLF range of operation 10 to 30 kHz, and tests at such a frequency represent the most severe condition in this range, a pass at this frequency assures a pass at any lower frequency, and hence VLF testing will not be required lower in the range. A plot plan is shown on p. 17 of NELC B228 ser 2100-86 of 30 May 1975.

1.3 Since performing the VLF tests will require the interfacing of several Navy organizations within NAVFAC, NAVELEX, and COMNAVTELCOM, as well as the Contractor, sufficient detailed description of the test procedures, (including equipment and personnel requirements, and data sheets which when filled out will comprise the final acceptance report date) is provided to give all concerned a clear idea of the methods, the schedule, and the end dates. Although for VLF some of the atmospheric correction factors have not been accepted as standard as for 60 Hz, the tests will be conducted in accordance with ANSI USAS C29.1 - 1961 (R 1969) C29.1a - 1971 and the corrections applied as therein set forth; however, three important exceptions are noted. 1. The wet and dry withstands are extended for 10 minutes and 1 hour (wet 1 hour at 300 kV is not a true withstand measurement, but a demonstration of freedom from arcover). 2. The direction of spray application during wet tests will not be in a 45° downward plunging direction, but will be at the discretion of the Test Director in any direction including horizontal. The method of determining delivery rate will be as in the ANSI procedures. 3. The corona detection observations will not be made with the unaided eye, since the test piece will be in an outdoor location and complete darkness as in an enclosure cannot be obtained; therefore 7 x 50 binoculars will be used.

1.4 In connection with flashover tests, visual observation will be supplemented by closed circuit TV/Video tape recording so that locations of arcs can be reliably determined. Although no specification requirement exists, it is obviously

desirable that arcs follow paths not immediately adjacent to porcelain members, and the existence of this condition will be determined.

1.5 During FY75 and FY76 there has been a series of failures in oil filled power supply capacitors in the FRT 64 and FRT 87 apparently associated with inclusion of air bubbles and subsequent formation of corona discharge and generation of hydrogen therefrom. Extensive investigative efforts within NAVELEX on the properties and handling of oil during filling and break-in and diagnostic testing indicate that it is important to select one of two, or at most three, brands of transformer oil for use at VLF in such devices in which fields of the order of 4.5 kV per millimeter exist. While the average field in (peak) the 12 inches of oil insulation is only 0.8 kV per mm in the I. U. to be tested, (rms) for a working voltage of 250 kV, the fields are far from uniform, and without (rms) analysis can only be assumed to approach the larger value at locations within the device near bends and corners of the components. In view of the experience with the capacitors, it seems desirable to make use of whatever diagnostic means exist to determine the probable presence or absence of corona inside the transformer, even though there is no clause in NAVFAC CHESDIV Specification 21-75-0043 requiring its absence.

The selection of the proper oil is important, because it is known that some oils are more susceptible to the problem than others, and in fact at least one brand of oil is certain to lead to catastrophic failure and should therefore be avoided. The diagnostic is important to indicate probable failure in advance of actual, so as to permit remedial action in the form of further degassification to take place.

The diagnostic means found most effective to date, though there are uncertainties in their application, is to sample the oil in a closed syringe for use either in a combustible gas analysis, conducted by Doble Engineering Co., or an analysis of residual unsaturated hydrocarbon bond concentration, conducted by Naval Weapons Center, China Lake. The actual diagnostic consists in comparing changes in the tested parameters before and after the test series. Consequently, provisions for oil sampling for the analysis are made in certain of the test plans.

The sampling is done on three occasions: 1, prior to wet withstand, to assess the original condition of the oil, 2, immediately after all flashover and corona tests, to determine the condition of the oil after the high voltage tests involving test levels higher than those expected in normal operation, and 3, at the conclusion of the extended heat run test, to compare condition with the test sequence conclusion both with the initial condition of the oil and with its condition immediately prior to the heat runs.

Although the three decks of the device are connected in common, the design admits very little circulation of oil between the decks. In consequence a separate sample of oil is taken from each deck, and a total of nine sampling syringes is therefore required.

1.6 Since the VLF Test Facility is a tuned circuit and not a commercial transformer, and is not a commercial installation and has not been certified by any measurements standards agency, considerable attention has been given to the details of the calibration procedure in the original test plan outline (B228 Ser 2100-86 30 May 75) so that all concerned can have understanding and convincing demonstration that the voltages applied during tests are indeed as claimed. This of considerable importance in the event that a test produces a marginal pass.

* Crest or peak value in The I.U. is
Thus 354 kV and 1160 kV/mm, about a quarter of That in capacitors

2. TESTS TO BE PERFORMED

2.1 The tests to be carried out are listed in the table below in their expected order of performance.

Test No.	Title	Contract Specification	Pass Value	Applicable ANSI C29.1
1	Facility Calibration	- -	- -	- -
2	One Hour Wet Withstand	21-75-C-0043 P00001 Para 7	300 kV rms	4.5 Low Freq Wet Withstand Voltage Tests
3	10 Minute Wet Withstand	None	Measure	" "
4	Wet Flashover	21-75-0043 3.8.6.1 P00001 Para 6	Not less than 360 kV rms	4.3 Low Freq Wet Flashover Voltage Tests
5	Wet Corona Inception/ Extinction	21-75-0045 3.8.6.4	Not less than 250 kV rms	4.10 Visual * Corona Test
6	10 Minute Dry Withstand	None	Measure	4.4 Low Freq Dry Withstand Voltage Tests
7	Dry Flashover	21-75-0043 3.8.6.2	Not less than 475 kV rms	4.2 Low Freq Dry Flashover Voltage Tests
8	Dry Inter-tier Grading	21-75-0043 P00001 Para 8	In propor-tion to indiv. rating	4.2 Tier by Tier using preset auxi-liary gaps
9	Dry Corona/Inception Extinction	21-75-0043 3.8.6.3	Not less than 285 kV rms	4.10 Visual Corona Test
10	24 Hour Heat Rise and Interruption Test Combination			
a.	300 kV Dry Heat Rise	21-75-0043 3.8.6.6	No more than 30° C over ambient	- -
b.	250 kV Wet Heat Rise	21-75-0043 3.8.6.5	No more than 30° C over ambient	- -
c.	250 kV Interruption Flashover (wet) with simultaneously applied 7 kV peak pulse	21-75-0043 P00001 Para 7	No more than 12 interrup-tions per 24 hours	- -

11	144 Hour Heat Rise with simultaneous 60 Hz full load, with 250 kV rms VIF	21-075-0043 Sect 2 General Requirements and 2.2.1 Integrated systems requirements	Continuous operation satisfying all other conditions of Test 10	- - -

2.2 Instrumentation of the Test Facility will consist of Instrumentation Packages #1 and #2, described and illustrated on pages 18 and 19 of NELC B228 Ser 2100-86 of 30 May 75. After system calibration, Package #1 in conjunction with base current meter indication at the transmitter console gives direct measurement of applied voltage during all tests. Package #2 permits the monitoring of number and duration of interruption events, during the 24-hour interruption test, as well as providing a means of voiding an interruption if it occurs during the application of a pulse exceeding the permitted 7 kV peak on top of the 250 kV rms (354 kV peak) VLF cw test voltage. Additionally, meteorological instruments, consisting of a pyschrometer and associated tables and curves, and an aneroid barometer, and herein referred to as Instrumentation Package #3, will provide the means to collect necessary atmospheric data for flashover corrections. All three packages are located in the Facility Test Control Hut inside the high voltage enclosure. Individual detailed test plans give the exact items needed. For some tests, such as facility calibration, other items are required. For completeness of record, sheets are supplied herewith to be filled in onsite listing all equipment actually used.

3. STANDARD WATER

3.1 Standard conductivity water for wet tests is available onsite in lots of 5000 gallons, replenishable at the rate of about 2000 gallons per day by use of an ion exchange resin process described on page 21 of NELC B228 Ser 2100-86 of 30 May 1975 or in Megatek Final Report "Testing of a Controlled Conductivity Water Source as Used in Testing Base Insulator Characteristics for VLF Transmitting Antennas," R2005-001-F-1 Contract N00123-75-C-0328 15 Dec 1974. Alternatively, it can be obtained by mixing station water with distilled water obtainable from SubBase, Pearl Harbor, in 3000 gallon lots. Delivery rate through the pumping system at the test facility when using ten standard spray nozzles is 1000 gallons per hour. By judicious use of an extra 4000 gallons of distilled water storage in the transmitter cooling system, approximately 12 hours continuous full rate delivery supply is available before a halt for replenishment is required. If, as is usual, the delivery rate is in proportion to the five nozzles commonly used, then approximately 3 1/2 days of water for continuous use is available. Since the test procedures envision only intermittent use of water up to about 4 hours maximum at a time, the available supply of standard water at this facility is essentially unlimited, and no interruptions in carrying out the test plan will be necessary for making up new standard water.

3.2 STANDARD WET SPRAY

Standard wet spray as used herein is defined in ANSI C68.1 Specific parameters derived therefrom are summarized below for ease of reference:

a) Direction of Spray - Downward at an angle of 45° from the vertical. BIA and protective system to be uniformly sprayed.
b) Rate of Precipitation - 0.2 inch/minute
c) Tolerance on Precipitation rate - At single measurement point, ±25%. Average of all measurement points, ±10%
d) Resistivity of Water - 7000 ohms per inch cube ±15% (17800 ohm-cm)
e) Water pressue (P) on Spray Nozzles - 35 <P<60 psi
f) Location of Spray Nozzles - Such that no flashovers shall occur to nozzles
g) Preliminary Wetting - The entire surface of the test sample will be wetted with standard water no more than one minute prior to electrical test
h) Position of Precipitation Rate Measuring Vessel -
   Separate measurements shall be made opposite the top, middle, and bottom of the specimen with the measuring vessel held in a line between the spray nozzles and the axis of the specimen, the side of the rim of the vessel being approximately 3 inches outside the largest diameter of the specimen. The vessel shall be held with its top opening horizontal.
i) Measuring Vessel -
   The precipitation measuring vessel shall have a top opening of 6 to 12 inches inside diameter with an upstanding rim at least one inch high having an edge thickness not exceeding 1/16 inch.

3.3 HORIZONTAL WET SPRAY

Horizontal wet spray as used herein provides for all conditions covered by Paragraph 3.2 above with the following exceptions:

a) Direction of Spray - Horizontal at the precipitation measuring points (ceramic surfaces of the BIA to be wetted by spray)
b) Position of Precipitation Rate Measuring Vessel -
   Separate measurements shall be made opposite the top, middle, and bottom of the specimen with the measuring vessel held in a line between the spray nozzles and the axis of the specimen, the side of the rim of the

4. INDIVIDUAL DETAILED TEST PLANS AND DATA SHEETS

4.1 STATIC ISOLATION UNIT, FACILITY CALIBRATION

4.2 STATIC ISOLATION UNIT, ONE HOUR WET WITHSTAND

4.3 STATIC ISOLATION UNIT, 10 MINUTE WET WITHSTAND

4.4 STATIC ISOLATION UNIT, WET FLASHOVER

4.5 STATIC ISOLATION UNIT, WET CORONA INCEPTION/EXTINCTION

4.6 STATIC ISOLATION UNIT, 10 MINUTE DRY WITHSTAND

4.7 STATIC ISOLATION UNIT, DRY FLASHOVER

4.8 STATIC ISOLATION UNIT, DRY INTER-TIER GRADING

4.9 DRY ISOLATION UNIT, DRY CORONA INCEPTION/EXTINCTION

4.10 DRY ISOLATION UNIT, 24 HOUR HEAT RISE AND INTERRUPTION TEST

4.11 DRY ISOLATION UNIT, 144 HOUR RF AND 60 HZ FULL LOAD HEAT RISE

2100

NAVAL ELECTRONICS LABORATORY CENTER
271 CATALINA BOULEVARD
SAN DIEGO, CALIFORNIA 92152
714-225-6011
AUTOVON 933-1011

IN REPLY REFER TO
NELC B228
ANS:rdl
Ser 2100-137
20 DEC 1975

From: Commander, Naval Electronics Laboratory Center
To: Commander, Naval Electronic Systems Command (PME 117)

Subj: Multiple Gap Base Insulator Protective Device, Final Development

Ref: (a) NELC ltr B228 ser 2100-69 of 6 May 1975
(b) NAVELEXSYSCOM ltr PME 117-223 ser 271 of 30 Sep 1975
(c) NAVELEXSYSCOM 141931Z NOV 75
(d) NAVCOMMSTA HONO 200018Z NOV 75
(e) NAVCOMMSTA HONO 250121Z NOV 75
(f) NAVELEXSYSCOM memo Code 510123 to PME 117 of 24 Nov 1975

Encl: (1) Summary sheet and sketch, MGD characteristics
(2) Final design development texts of VLF multiple gap protective device

1. Reference (a) outlines principles of operation of the NELC/NBS Multiple Gap Protective Device (MGD) and summarizes VLF and impulse behavior of a prototype. Information therein was stated to be sufficient to permit installation of a final version without further tests except those required for final adjustment at the various sites.

2. By reference (b) NAVELEXSYSCOM continued the MGD finalization as item 96 of Circuit Charger, and after an exchange of informal memos by ELEX Code 510123 and NELC Code 2100, the test plan of reference (c) was implemented as a follow-on to VLF tests on the static isolation transformer. Results of these tests were briefly summarized in references (d) and (e), and the earlier recommendation of reference (a) to use configuration #8 or a closely related development version thereof was confirmed.

3. In view of doubt engendered by reference (f) on suitability of this configuration in preference to another apparently showing higher VLF withstand characteristics, the program of reference (c) was considerably expanded by the NELC Test Director, and the data base was sufficient upon detailed analysis to show that as previously stated configuration #8 is indeed the desired MGD arrangement. This is an eleven-tier bank of partially graded rod-plane gaps whose spacing has been tailored to fit the operating requirements of the tower base environment at Annapolis and Lualualei VLF communication transmitting antennas; it is noted that the recommended MGD of reference (a) fits the actual operating conditions of both stations at their normal broadcast frequencies with a considerable safety factor, although the margin at the lowest possible VLF

frequencies is small. The "growth" version of MGD #8 is in this respect somewhat better suited for Lualualei. In support of the above, enclosure (1) is herewith forwarded for information and retention. It is further noted that the recommended MGD is compatible with either choice of accessory tower lighting mechanisms, whether the existing rotary unit or the new transformer. With only a minor further readjustment, #8 can be made compatible with the Omega tower base insulator.

4. Configuration #10 and all related rod-rod configurations have higher withstand and flashover voltage levels for given electrode spacing, but this is no advantage since reduction of tested levels to those compatible with application of the MGD to protecting the smaller insulators requires use of gap spacing possibly allowing connected water streams in extremely wet and windy conditions. There is a greater spread in activation level wet versus dry, for the rod-rod geometry, compared to the rod-plane electrode; thus the latter has the advantage of more predictable behavior regardless of weather. Upon assignment of withstand levels for wet operation, the rod-rod MGD in consequence stresses the insulator stack more highly for dry withstand than does the rod-plane MGD, and in consequence the life expectancy of insulators in the #8 configuration is greater. Enclosure (2) gives the details of the comparison of the five major configurations and their 14 minor variants that were tested.

5. Configuration 8a is recommended for use at normal operating frequencies at both Lualualei and Annapolis. If full-power operation at 14.7 kHz is desired at Lualualei, configuration 8b or the refined version, 8c, will be required. In view of the limits imposed by the present insulator at Annapolis, 8a is adequate for all conditions at that site. Because of the reduced performance of the tower base insulator in the LaMoure and Argentina Omega installation due to the smaller flashover distance resulting from the rainshield geometry, configuration 8a with the gap string settings reduced by 16% will be required.

6. Assembly experience in the field has shown that after appropriate site preparation has been accomplished, erection of the device on the foundation pad by a properly trained crew of 4 antenna mechanics can be accomplished within the usual 6-hour weekly maintenance period working with a prepared kit of prefabricated parts.

NELC B228
ANS:rdl
Ser 2100-137

7. NELC is prepared to finalize working installation and assembly drawings and procurement specifications for the MGD.

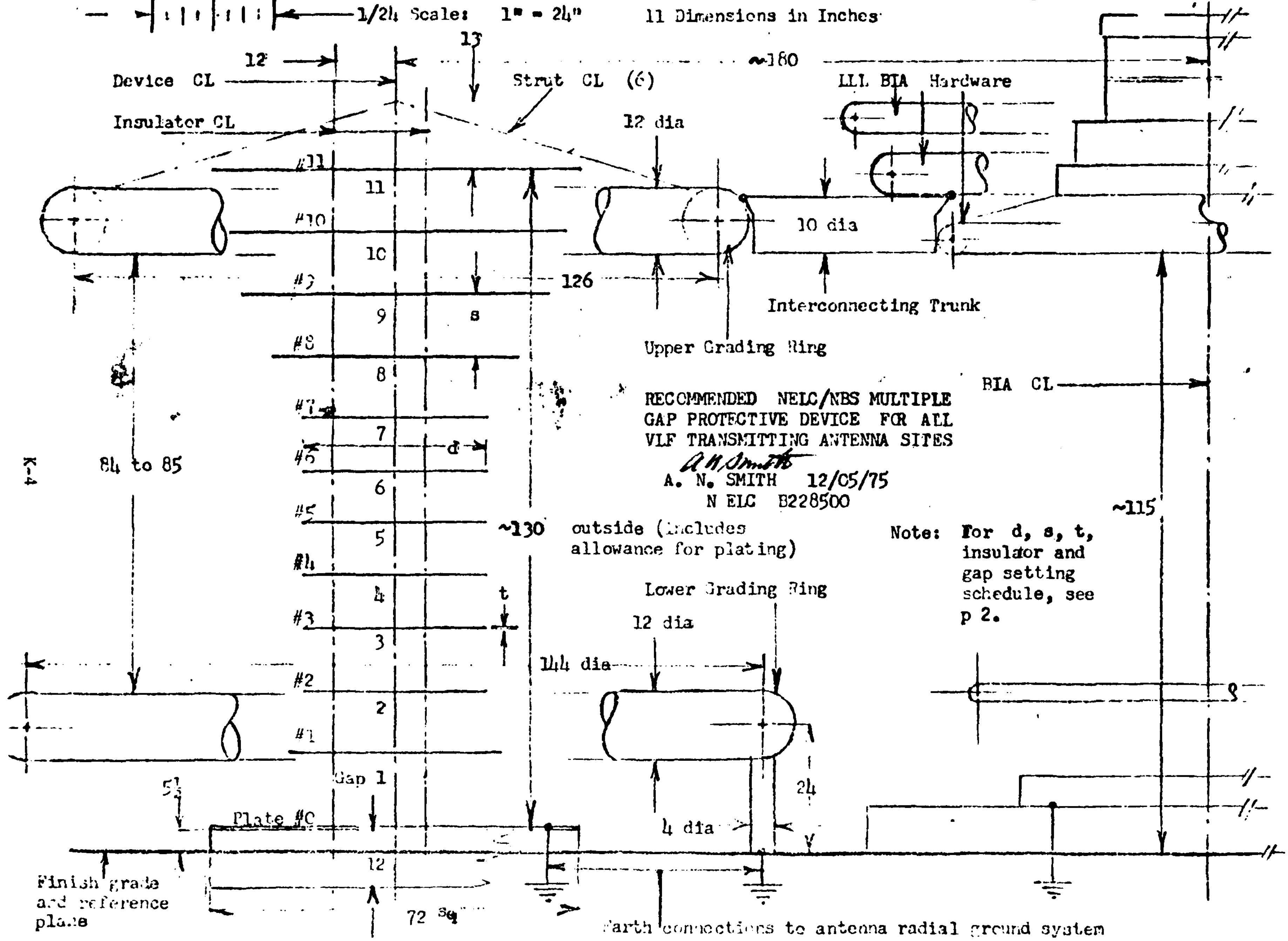
Charles A Nelson
C. A. NELSON
By direction

Copy to: (w/encls)
NAVSEEACTPAC
NAVELEXSYSCOM (51012, PME 119)
NAVELECSYSENGCEN WASH DC
COMNAVFACENGCOM (PC-6)
NAVFACCHESDIV (FPO-2)
NBS High Voltage Lab (F. R. Kotter)
NAVCOMMSTA HONO NRTF Lualualei
NRTF, Annapolis MD
COMNAVTELCOM

2100 (3) (w/encls)
1300 "
2020 "
2040 "
6860 (4) (w/o encls)

Prepared by: A. N. Smith, Code 2100, Ext. 7303
Typed by: R. D. Lanning, Ext. 7302, 17 December 1975

ENCL (1) p 1



RECOMMENDED NELC/NBS MULTIPLE GAP PROTECTIVE DEVICE FOR ALL VLF TRANSMITTING ANTENNA SITES

A. N. Smith

A. N. SMITH 12/05/75
N ELC B228500

Note: For d, s, t, insulator and gap setting schedule, see p 2.

Enclosure (1) to NELC ltr ser 2100-137 of Dec 1975

SCHEDULE OF MGD DIMENSIONS
AND ELECTRICAL CHARACTERISTICS

Plate	Thickness t **	Diameter d	Separation s		Insulator**		Gap Spacing g 8a	8 b	8 c	10 d
11	¼	72	12	12	37723	37723	2½	2-3/4	2-7/8	2-1/8
10	1/16	66	12	12	37723	"	2½	2-3/4	2-13/16	2-1/8
9	1/16	60	12	12	37723	"	2¼	2½	2-9/16	1-7/8
8	1/16	48	12	10	37723	37715	1-3/4	2	2-3/16	1-5/8
7	1/8	36	10	10	37715	"	1½	1-3/4	2-1/16	1-9/16
6	1/8	36	10	10	37715	"	1½	1-3/4	1-15/16	1½
5	1/8	36	10	10	37715	"	1½	1-3/4	1-7/8	1½
4	¼	36	10½*	10	38720*	"	1½	1-3/4	1-7/8	1½
3	¼	36	12	12	34040	37723	1½	1-3/4	1-7/8	1½
2	¼	36	12	15	34040	37714	1½	1-3/4	1-7/8	1½
1	½	42	14½	18	31152	37746	1½	1-3/4	1-7/8	1½
0	3/4	72 sq.								
			---		----		---	---	---	---

*Includes 5" to 3" b.c. ½" thck adapter plate. **This set for 8c & 10d only.
Boxed figures are configs actually measured. Electrodes all ½" dia, hemispherical ends.

ELECTRICAL PERFORMANCE COMPARISONS, MGD,
VERSUS TOWER BASE COMPONENT REQUIREMENTS

Characteristic		MGD Configuration 8 a	8 b	8 c	10 d	Tower Base Component LLL BIA		ANNAP BIA		OMEGA BIA		LAPP I.U.#	AOA. I.T.	
DFO		260	280	320*	370**	510		440		400		424	475	335++
DWS		240	270	310*	335**	475		---		---		398	360	300++
DI	100	440	510 *	570 *	550 **	---		---		---		---	---	
	50	430	490 *	550 *	520 **	---		---		----		---	---	
	0	420	(470)*	(530)*	(490)**	1700	800+	---		---		---	800#	
WFO		260	280	320*	330 **	390		268		250		354	381	315++
WWS		242	265	305*	300 **	320 (250+ inter. free)	300+	250	220+	210	250+	295	340 (250+ int. f	300++
WI	100	410	470 *	530 *	540 **	---		---		---		---	---	
	50	390	450 *	510 *	510 **	---		---		---		---	---	
	0	(370)	(430)*	(490)*	(480)**	950	800+	---		---		---	800#	

*Calc from 8a or 8b. **Calc from 10a or 10c. +Required
Figs in parens inferred from 100% & 50% FO data.
Witnstands (WS) are for 1 hr except as noted. All figures except Impulse (I) are rms. 100/50/0 desig. are % occurences

#With mod #2 NPLC grading ring as presently installed LLL & ANNAP.

Required
++With 16" gap

FINAL DESIGN DEVELOPMENT TESTS OF VLF MULTIPLE GAP PROTECTIVE DEVICE

A. N. SMITH

15 December 1975

Principles of operation of the NELC/NBS Multiple Gap Device (MGD) have been outlined, and experimental results of tests on various prototype configurations at VLF have been reported by NBS,(1). A selection of prototype variations was tested for impulse behavior by NELC and NBS on a Marx generator at NATC Patuxent River in April of 1975. Test results were reported (2) along with a review of requirements for the device in its contemplated application for diversion of lightning discharges from tower base insulators, and rather specific recommendations were made concerning the final electrode arrangement and gap settings, related to the specific installations where the device is to be applied. At the time of these recommendations it was recognized that a final series of VLF tests should be carried out to confirm compatibility of the device in its last configuration with tower base device characteristics, since there were some differences between the geometry used in the then last VLF tests versus the impulse tests, and there was a significant change in insulator stack. However, not until September of 1975 did the probability exist that such a final series of tests would be carried out.

At that time it became apparent that the time allowed for testing a new tower lighting VLF/60 Hz power isolation transformer would permit some parallel effort on the final version of the MGD, unless unforeseen development effort became necessary on the transformer. Accordingly a test plan was developed by NELC Code 2130 and NAVELEXSYSCOM Code 510123 addressing dry flashover, wet flashover, wet withstand, and interruption tests of those configurations thought to be, as a result of the previous tests, most nearly suited to give required protection to base insulators and isolation units at Lualualei, Annapolis, La Moure, and Argentina. This plan was promulgated as an instruction to NELC (3); its scope was later extended (4), (5), in order to permit as detailed a study and comparison as possible of all likely configurations of interest. In particular, extended withstand tests were de-emphasized and their probable results calculated as predictions based on other related experience; and the 24-hour interruption-free test at 250 kV was dropped completely in favor of a series of tests of inter-tier grading, and a study of corona inception behavior.

Because the Patuxent River impulse tests indicated that a stack of 11 tiers or fewer, properly graded, would suffice, the version erected at Lualualei for the final test series consisted of 11 instead of the 13 tier geometry used before. Five major variants, of which four involved different combinations of active tiers, were tested; within each variant as many as three changes in gap setting were used. The numbering scheme refers directly to that used in reference (2): #8 is the identical rod-plane arrangement tested at Patuxent River,

#9 and #10 are the eight-and eleven-tier rod-rod configurations (#10 and #8 share the same deck sequence, with only the electrode geometry differing significantly, while #9 is a foreshortened variant of #10). Configurations #11 and #12 are new, in that the first is a rod-rod 9-tier version of #7 of reference (2), while #12 is an "inverted" version of #9. Figures 1 and 2 herewith completely define the geometry of the decks and the various electrode spacings used.

As will become evident, the upper limit of continuous operations is determined in part by the selection of the insulators on which the array of gaps is mounted. These were selected on the basis of cost, ease of handling, simplicity of structure, limit on bulk, and on rating required to withstand voltages expected as well as structural considerations, primarily working limit on shear loading brought about by wind and vortex shedding. The voltage at which the device provides protection is then set by the adjustment of the gaps and in part by the determination due to their physical type. This level is distributed over the individual gaps and insulator decks by the grading due to the capacity tier-by-tier to the outside world, and hopefully no individual insulator is stressed at the gap withstand to a level above the working rating of the insulators. The actual breakdown of the assembly is of course determined by the most highly stressed gap, regardless of its *actual spacing*, all other conditions being equal, provided the gaps are all adjusted to a range of spacings where they act similarly. That is, if deck #5 has due to capacity grading 24 kV on it and the gap is set to 1-1/2 inches while #11 has 36 kV on it and the gap is set to 2-1/2 inches, #5 would be controlling, whereas if #11 were reset to 2 inches it would become controlling (assuming all other gaps were not so highly stressed in kV per cm of separation). The ideal situation is to set the gaps in proportion to the capacity grading, so that no one is more likely to control the behavior of the string. The simplest situation is to equalize the grading so all gaps can be set the same, but this may not be easy to do in a practical sense. In re-adjusting the gaps so as to arrive at some new overall protection limit, due regard must be given to the grading to determine which gap is controlling in the old situation, and which one will become controlling in the new. This is the basis on which the tables have been constructed that predict the behavior of the refined version of the two configurations that finally appeared to be most promising. Also, in re-adjusting overall response levels, attention must be paid to the working stress on the insulators, especially if the level is to be raised.

The ratio between withstand levels wet versus dry is in part dependent on gap type. It appeared that within the range of spacings employed the rod-plane gap displayed behavior less dependent on environment than did the rod-rod gap, although for the latter a shorter total separation can still yield a higher dry flashover level than an assembly using rod-plane gaps. This is in itself no particular advantage since the ratings of the individual insulators may thereby be exceeded. This was in fact the case for some of the configurations and gap settings studied, and led in one instance to a failure in an insulator.

Table 1 is a compilation of all the characteristics measured during the test series run at VLF during the period 17 through 21 November 1975. The flashovers were run in accordance with ANSI C29.1 procedures, as were the withstands, except that those cases of the latter actually measured were extended in time period from 10 minutes to in some case 40 minutes. The flashover values quoted are corrected from applicable atmospheric conditions, and then rounded off in some cases downward where more than one trial sequence yielded a significantly smaller result. The withstand values quoted are long-term levels estimated as 90% of a withstand observed for 5 to 15 minutes, and 95% of those observed for 20 minutes or more. These factors are based on experience observed in testing devices of various sorts, including gaps, over a period of the last three years. This expedient was adopted because of the extreme limit on available time for the test series, which limit did not permit running extended long-term withstands. Where no actual data was taken for a given configuration, an estimate was made interpolation from the behavior of some similar configuration, or else interpolated on the basis of a likely mode of variation with settings appropriate for the range used. This appeared to be something between linear and square law.[1] Figures arrived at in this manner are enclosed in parentheses. Impulse test results were treated in a similar manner, based on results observed and reported in reference (2). It is noted that three impulse levels are listed, (all for negative polarity, as those for positive are higher in absolute value) namely levels for 100% flash occurrence, 50%, and no flashover. The first two levels were the best values obtainable, where experimental data was actually run, resulting from the statistical approach required by the ANSI procedures. The third or zero occurrence level is in every case quoted here surmised on the assumption of normal distribution about the 50% level.

Obviously the selection of a configuration for the protective device must satisfy the following requirements:

1. VLF flashover, and withstand must be higher by some desired factor than either or both of:

a. The interruption-free wet operation requirement for the device being protected, typically 250 kV

b. The actual operating voltage level of the insulator being protected at a particular installation at full power at a specified frequency.

2. Operation must either be corona free wet or at worst corona and local heating effects consequent thereto must not be destructive or lead to system interruption if a failure occurs

3. Impulse withstand level for zero events must be higher than the levels mentioned in item 1 above, and for 100% events must be below the withstand level for the device being protected (for zero events for it).

4. Flashover of any individual gap for either VLF surges or overload or for impulse application should lead to cascade of all the other gaps, so that no sustained "welding" type arc can exist in an individual tier without the rest of the gaps firing.

5. An insulator failure in any one tier should not lead to flashover of the entire assembly at normal system operating voltages, and should not result in catastrophic mechanical failure of the pretective device.

6. Operation of the device at either of its withstand limits should not result in overstress of any individual insulator in the stack, for that environmental condition. If under this condition corona exists, it should satisfy item 2 above.

7. To assure item 4, the unit stress of all gaps should be equalized, that is each individual gap should be adjusted for a flashover level in the same proportion in relation to those of the other gaps as is the capacity grading. Fulfillment of this condition does not require actual equalization of the grading.

8. Though not an absolute requirement, it is highly desirable that the behavior of the protective device be immune to changes in environmental conditions, for example, dry conditions versus blowing rain and mist. The voltage response of the device must satisfy all above conditions, particularly 1 and 3, for the least favorable environmental condition for the device being protected, even though the desirable condition of equality of behavior wet versus dry is not completely met by the protective device.

9. Attainment of item 7 has the further advantage of maximizing the arcover level of the device for a given selection of total gap separation, since in this case no one gap is controlling through having reached its critical stress level earlier than any of the others.

10. The device selected should be as universally applicable with a minimum of readjustment as possible, to all installations and for all parts of the frequency range to be used.

From Table 1 it is noted immediately that all configurations tested except those involving the larger gap spacings for #10 satisfy items one and three for the Lualaulei BIA and for the isolation transformer. If application to Annapolis and to either of the Omega installations is desired, then the range of allowable gap settings becomes more limited to the smaller end of the tested adjustment range. The table does not address item 2, but it is noted that for the pin-cap insulators used the device was corona free at all levels of interest dry, while wet the insulators displayed corona around the top cap grout joint at levels about half the withstand although the corona did not become severe enough to be of concern until levels above that at which the BIA was to be protected were reached.

Figure three shows the absolute grading. From this, and from a similar plot of grading normalized to unity for the least stressed insulator configuration

#11 is seen as the most uniform, with #8 and #10 the next, and #9 the worst with #12 intermediate. However, if the rating of the insulators is taken into account, the development of a table like table 2 shows that the most favorable grading distribution without extensive rework is #8 and #10. This would be so even if the bottom two insulators were replaced with the 12 inch types like 37723. While #11 could be made to function almost as well as #8 or #10, it is evident that even in the case of perfectly uniform grading the unit stress per insulator would be at least 9% higher than an equally well graded version of the other two and as the data finally indicate for the optimized gap spacings, the insulators would in consequence be operated that much closer to their limiting ratings. For this reason alone #11 is rejected.

Configuration #9 was carried along in the data analysis as a sort of worst case, and comments concerning it apply almost equally well to #12. Although #9 looked promising as a result of the impulse tests in terms of the rating attained versus the relatively fewer number of decks, the data analysis indicates that serious overstress existed in the version tested (due to faulty grading), to the extent that one of the 37723 types failed. Even if perfectly graded, with the present insulator selection there is no way to operate continuously in a safe relationship to insulator ratings at VLF and offer the degree of protection desired. It could be improved in this respect by selection of larger insulators, but it then would lose whatever advantage in cost it would otherwise have over #8 or #10.

Considerations such as the above lead to investigation of the choice of insulator types other than pin-cap to see if higher voltage ratings were available for insulators occupying the same vertical space per deck. The only candidate appeared to be existing porcelain station posts, but no production version of such in the desired size appeared to be available that offered in one unit the desired voltage and horizontal mechanical shear ratings with the use of an end cap casting permitting outside-exposed bolt heads without use of special adapter plates. Existing experimental posts employing exotic and/or novel materials such as epoxy or other organic-encapsulated fiberglass compression members were rejected on basis of non-availability for commercial purposes.

Tables 3 and 4 show how estimated performance can be improved by refining the relationship of gap setting to grading and insulator rating. The projection of characteristics is based on prediction of individual gap behavior with reference to unit stress, the objective being to stress the gaps equally. It can be seen that configuration #8 in its various versions comes the closest to meeting performance requirements imposed by the application to the VLF communication stations, and in a version in which the gaps are slightly shortended will meet the Omega station requirements as well, when the actual performance of the various base insulators is taken into account. These relationships are summarized in the table of page 2 of enclosure (1) to the present covering letter. #10 gives apparently better dry performance but with no substantial improvement wet, and only does so at the risk of increased stress on the individual insulators in the assembly, unless larger insulators are used. Table 5 gives the detailed performance comparisons. It should

be noted that conceptually configuration #10 could be adjusted for reduced flashover and withstand characteristics dry, but this would also reduce the wet characteristics and furthermore require spacings sufficiently close that either significant danger would exist that connected streams of water could flow across the gap or else require further developmental investigation about the properties of other rod-rod geometries that would prevent this but whose electrical characteristics are unknown. Use of configuration #8 has the advantage that the behavior of the rod-plane gap is sufficiently well defined over the range of adjustment being considered here that no further development is needed. A final rendering of configuration #8 is shown in page 1 of enclosure (1). It is noted that the plates are to be made of either zinc galvanized or cadmium plated steel, of the thicknesses shown for additional shear rigidity, and the electrodes are made up of stainless steel 1/2" diameter rounds with hemispherical ends, segmented in 1/2" long modules if desired for adjustment purposes. Figure 4 shows a comparison of the ratio of insulator stress versus rating for the final versions of #8 and #10 at their highest settings.

While other gap arrangements and combinations of gap separations can be imagined, and in fact have been looked at, it appears that the rod-plane type is the simplest and most natural form of self-grading geometry available, and furthermore in the spacings employed shows the greatest predictability in behavior.

All VLF and impulse testing carried out on the MGD since May 1974 has been done with the device connected in parallel with a mockup of the BIA of the Lualualei type. The interconnection employed has been a trunk longer than any contemplated in the final "production" version, and hence no problem is expected in the definition of the discharge path in virtue of distribution of trunk series inductance, since this has always been larger in the experimental version. In no case up to now has any discharge been observed to take place other than in the gaps at either impulse or VLF.

In summary, configuration #8 in its highest rated form will withstand 300 kV wet, flash at 315 kV dry, (rms), provide negative impulse protection in the range 500 kV (zero events) to 540 kV (100% events) wet, and about 580 kV dry for 100% events. Under continous duty at wet withstand no insulator in the set will be stressed to more than 85% its long-term 60 Hz withstand rating, and under actual conditions of full power use in the most usual severest condition (23.4 kHz, full power, east tower at Lualualei, voltage is 208 kV) the ratio is not over 60%. For this condition, wet operation is not corona free, but such corona as will exist is not severe.

A modified configuration #10 will permit satisfactory but less predictable performance wet versus dry, with somewhat higher insulator stress at its dry withstand level. As described in reference (2), it is unsatisfactory since it withstands to levels such as to overload the individual insulators, and the dry VLF withstands are too high in relation to the levels it is desired to provide protection to some of the base insulators.

REFERENCES

1. National Bureau of Standards Report NBSIR 75-731, "A Study of Air-Gap Breakdown at 28.5 Kilohertz," By F. R. Kotter, Electricity Division, Institute for Basic Standards, 20 June 1975.

2. "Prototype Multiple Gap Device Impulse Tests,"by A. N. Smith, Enclosure (1) to NELC ltr ser B228 ANS:rdl 2100-69 of 6 May 1975.

3. NAVELEXSYSCOM 141931Z NOV 75

4. NAVCOMMSTA HONO 200018Z NOV 75

5. NAVCOMMSTA HONO 250121Z NOV 75.

MEGATEK CORPORATION

FINAL REPORT

Title	:	Impulse Testing of Rod to Rod and Rod to Plane Protective Gaps for VLF Antenna Systems.
Number	:	R2005-021-F-1
Contract No.	:	N00123-75-C-0328
NELC Task	:	MEG TA-022
Date	:	30 May 1975

Submitted to:

Naval Electronics Laboratory Center
Code 2160
San Diego, California 92152

Prepared by:

C. J. Pitt

1.0 BACKGROUND

The insulators in VLF antenna systems and antenna tower lighting isolation units require protection from high voltage arc-overs caused by output from the high power VLF transmitter and/or from external lightning discharges striking the antenna system. Ball gaps (uniform field gaps) offer protection of the equipment if spacing is set for either wet or dry conditions. However, with a given gap setting ball gaps do not offer adequate protection under both wet and dry conditions.

2.0 APPROACH

The high voltage impulse generator at the Naval Air Test Center at Patuxent River, Maryland, was used to determine the characteristics of multiple "rod to rod" and "rod to plane" gaps under lightning or impulse conditions. Ten different gap configurations were tested with various gap settings, rod sizes, number of gaps, and placement of grading rings.

3.0 RESULTS

An attempt was made to measure the grading on the gap stack with a 100 kV 60 Hz transformer. This measurement was not successful since the capacitive reactance between the plates of the stack was too high to offer any appreciable capacity grading. Voltage distribution on the stack in this case is determined by the leakage resistance across the supporting insulators. However, at VLF frequencies the capacitive reactance, between the plates of the gap stack, is lower and does determine the grading on the stack. This was substantiated at the Lualualei Test Facility in Hawaii. Seawater sprayed on a base insulator did not change the grading on the insulator indicating that it was, in fact, capacity graded.

Figures 1 through 8 show the configuration of "rod to plane" gaps tested at VLF frequencies. Figure 9 and 10 show the configuration of "rod to rod" gaps. (Rods from 1/2" to 3/4" in diameter with rounded ends were used).

Table 1 presents a summary of "rod to rod" data taken. Table 2 presents a summary of "rod to plane" data taken.

Oscilloscope pictures were taken for each arc-over of the gap. These pictures show the rise and decay of the pulse and were retained by the NELC Test Engineer for study.

4.0 CONCLUSIONS

This series of impulse tests demostrate that "rod to rod" and/or "rod to plane" gaps will protect the antenna system at VLF frequencies under both wet and dry conditions with a single setting of the gap. It was found that there is only a very small difference in the arc-over potential under wet or dry conditions of "rod to rod" and "rod to plane" gaps at VLF frequencies.

The "rod to rod" and "rod to plane" gaps are, therefore, suitable for protecting the VLF antenna and the associated equipment from lightning discharges.

The Figure 8 gap configuration is suitable for protecting the towers at NAVCOMSTA Lualualei.

The Figure 9 configuration is suitable for protecting the Annapolis and OMEGA 1200 foot antenna systems.

5.0 RECOMENDATIONS

It is recomended that if such gap systems (as shown in Figure 8 and 9) are integrated into the VLF antenna systems, that they be modeled in an electrolytic tank, or some other field mapping scheme, to determine the optimum size and placement of the corona rings and field shaping plates before the final design of the protective gap system is undertaken.

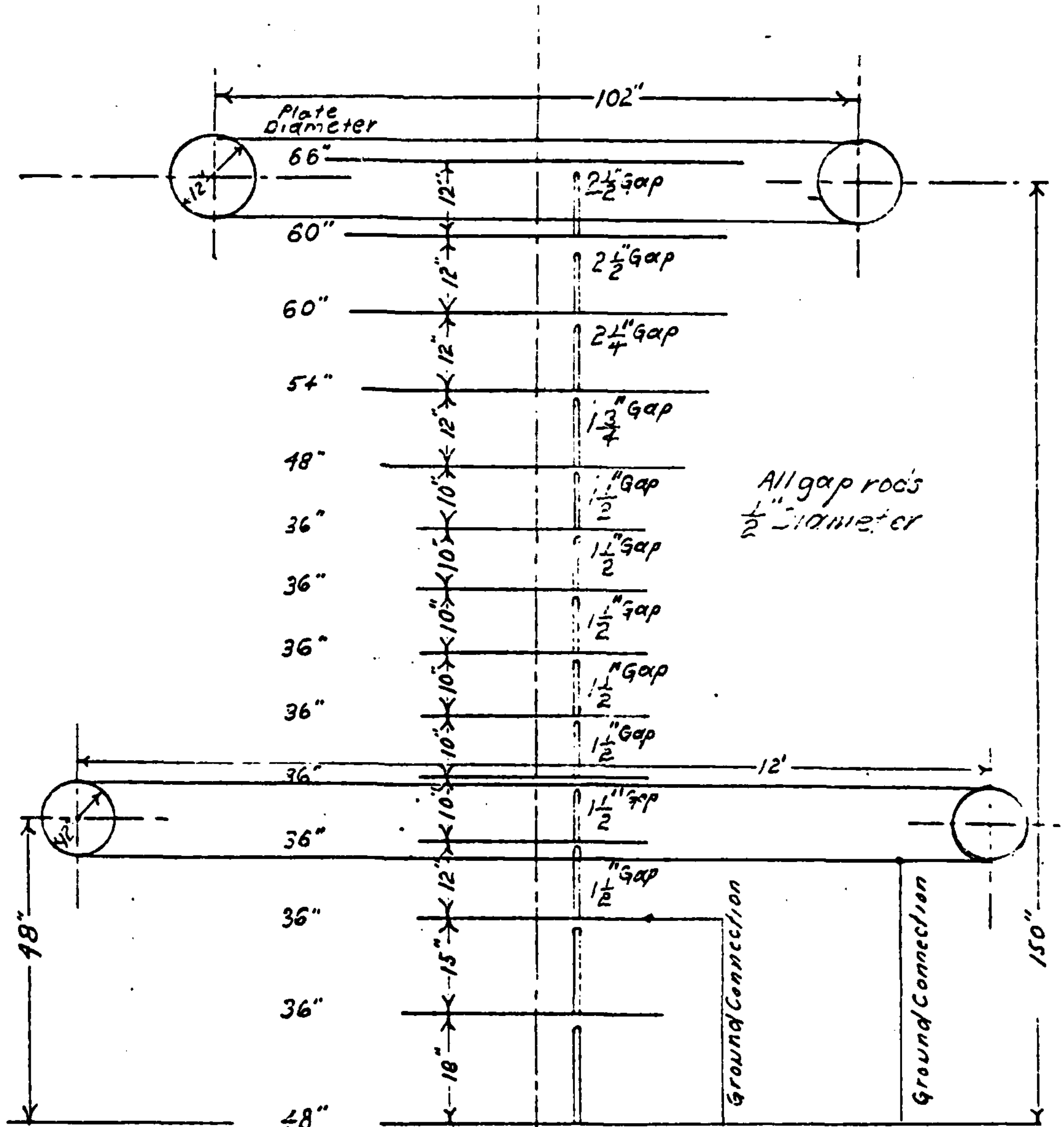


Figure 8 Protective Rod Gap Configuration Suitable For Protection of LuaLuaLei Antenna System (Configuration 8)

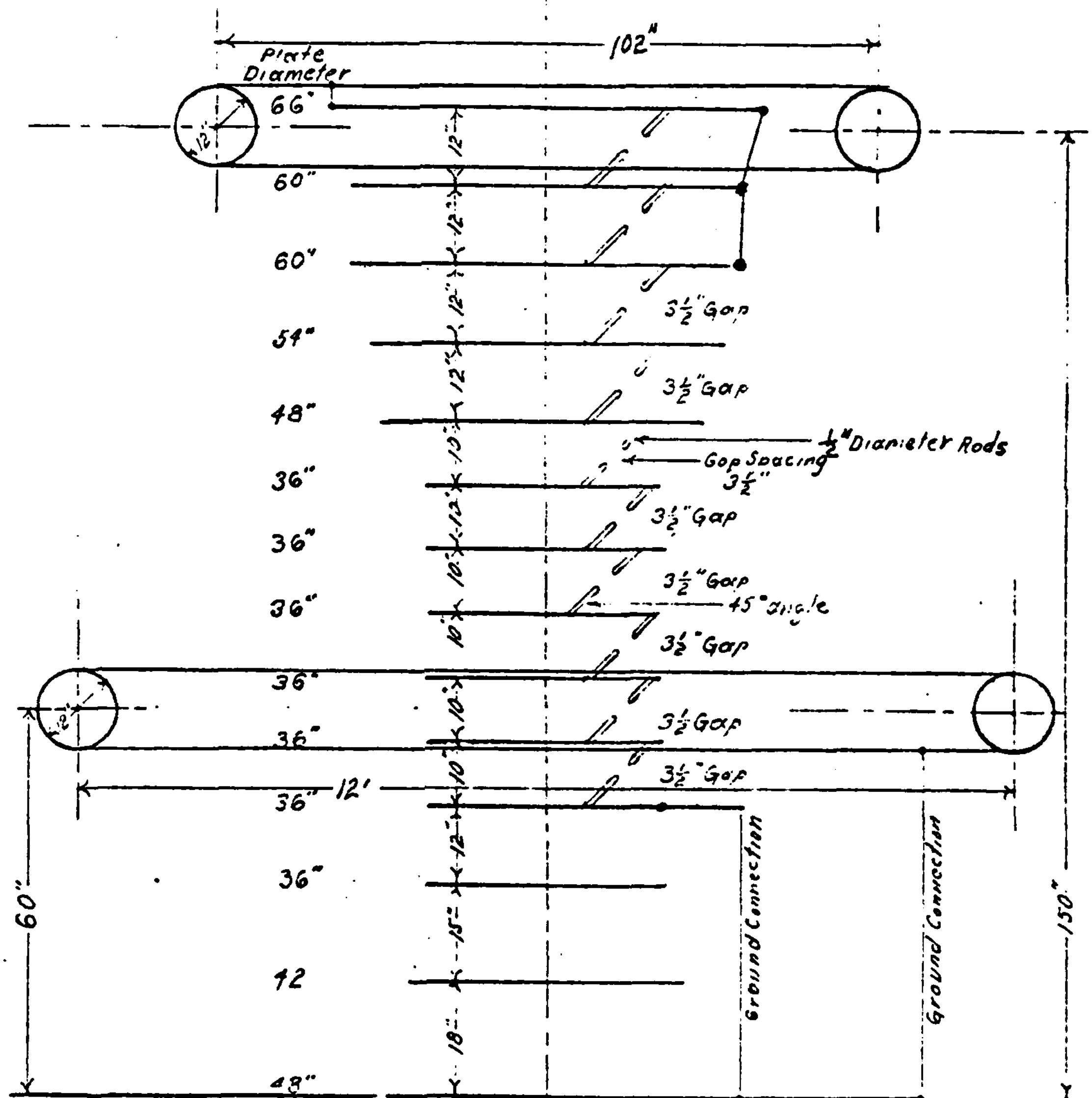


Figure 9 Protective Rod gap Configuration Suitable For Protection Of Annapolis and And 1200 Ft Omega Antenna Systems (Configuration 9)

TRIP REPORT
1 ND-GEN-5050/1 (12-65) 0190-029-5100

This is your official report to the office which assigned you the trip. You are requested to provide answers to the questions listed below within 5 working days of your return. Be specific and concise. Be candid in reporting observations, problems, recommendations.

a. Did you make commitments – personal, unofficial, or official? Yes

b. Were classified subjects discussed? If so, what? Classify this report, if necessary. No

TRAVELER (Name, Title, Grade, Code)	INCLUSIVE DATES OF TRAVEL
Andrew N. Smith Physicist, GS-14 Code 2160	10 Nov – 17 Nov 74
OTHER TRAVELERS (If report includes all information)	PURPOSE OF VISIT
	Observe and participate in Omega Haiku topload span inspection for electrical damage

PLACES VISITED	DATES	PERSONS CONTACTED (Name and Position)
OICC MIDPAC	11/14/74	CAPT K. Brooks, LCDR W Currie, OICC and deputy OICC MIDPAC
Omega Nav Sta Haiku	11/10/74 — 11/16/74	E. J. Ralph, R. Campbell } OICC MIDPAC Staff
Coast Guard Operational Detail	"	CDR C. Sherrod NAVFAC HQ PC-6
		J. Pellett, Holmes & Narver; B. G. Hagaman, Westighouse
		W. Workman, W Carter, R. Hudson } Tower Inspectors Inc.
		M. Springel, Onsod Staff

SUBJECTS DISCUSSED (Observations, Problems, Recommendations, Commitments, etc.)

LT Harris, Coastguard OIC Onsod
Emanuel Coltatn, Wheeler Industries
B. Cottrell, Pearl Harbor Naval Shipyard
W. Bassama, PME 119 Project office

1. Background for this trip was a sequence of events starting April 74 involving obstruction markers and vibration dampers on spans at Haiku Omega Navigation station. Initial full power trials took place not long after electrical storm event in April 74 during which possible strike or surge took place on spans. During initial testing, two markers burned and fell from spans. As result of RF tests conducted by oversigned at Lualualei NV facility, decision was taken to remove markers from active portion of spans, and allow markers on grounded haliards to remain. Contractor that removed markers reported evidence of damage to span cable in neighborhood of vibration dampers suggestive of arc damage. In consequence, oversigned was requested to test vibration dampers at high voltage levels at Lualualei; contrary to obstruction damper test results, vibration damper tests led to no evidence that cable damage was necessarily attributable to arcing. NAVFAC let new contract to Tower Inspectors to conduct detailed examination of all Haiku spans, and oversigned was invited to participate in planning, acts as consultant during execution, and interpret results, of span inspection. Program included verbal reports, photographs, sketches and tracings of damage and location thereof, also measurment of ground resistance and ground return currents at the haliard terminations.

2. During reported period, three attempts were made to inspect span 6, none

SIGNATURE OF TRAVELER | DATE 11/27/74

COPY TO: ~~Code 2000, 2200, 2300, PME 117, 119, Chamdiv PTO-2, NAVFAC PC-6,~~
PACNAVFACENGCOM, OICC MIDPAC

TRAVELER	PLACE VISITED
Andrew N. Smith	Omega Haiku, OICC MIDPAC

SUBJECTS DISCUSSED (Continued)

succeeding in making a complete traverse of span 6 to its center, although one pass attained the high voltage end of the main span insulator. Detailed logs were kept on the ground of alll verbal description of surface imperfections by the inspection team, and the team photographed all such areas. Most significant items found were pits in the haliard strands at the former location of the obstruction marker, what were finally interpreted as abrasions on the cable surface between members of the third group of vibration dampers, and "weld rod spatters" on two of the small corona rings on the ground side of the span insulator set. Additionally, whitish corrosion-like discoloration, subsequently attributed to packing material adhering to the surface, was observed on some of the damper weights; and a dark discoloration due to a material described as resembling fungus or moss was found on the lowermost extremities of insulator petticoats (this was cleaned off). Nothing was found that could reasonably be attributed to high potential arcing phenomena with the possible exception of the surface defects on the corona rings, and this could be explained as a byproduct of a modification process carried out in the field during assembly. Circumferential abrasions were also found on the haliard cable; these appeared to be caused by possible rotation of vibration damper mounting clamps during assembly.

3. Two obstruction markers that had been on the spans and subsequently removed were examined for possible electrical damage. Both showed positive evidence in the form of charring and tracking in the epoxy-bonded fiberglass walls in the portion immediately around the imbedded ends of the preformed wire clamps used to support the markers on the cable. Additionally, one of the two showed unmistakable burning around the periphery along the joint line between the two hemispheres and on the molded pads accommodating the bolt locations for joining the two halves. This burning and tracking was identical in nature to that observed as a result of VLF testing by the oversigned in August at Lualualei. These tests indicated that initiation of burning must take place at higher normal surface gradients than normally attained during operation of the spans, but that after such initiation takes place, subsequent progressive deterioration and final destruction from burning can and does take place at usual operating levels for gradient. The inference is that the initiation of the damage at Haiku probably took place during a lightning-induced surge, and that final destruction resulted during high power operation subsequent to that event. Pits were found in the wires of the preformed steel clamp similar in nature to those found on the haliard; surface configuration and surrounding raised corrosion areas initially suggested the pits could have been formed from high localized temperatures. The clamps concerned were taken to the Metallurgical Lab at Pearl Harbor for examination and test; result was that pitting was held to be from mechanical wear and salt-air corrosion, not electrically induced heating such as might take place during a very heavy corona flare as a result of a surge. This conclusion does not invalidate the supposition that the observed burn damage takes place during a lightning surge but does indicate that the current flow outward from the marker is insufficient to heat the metal to the softening point. Assumption of mechanical wear for the cause of pitting means that significant energy from span vibration is dissipated in the assembly, and that it gains entry across a clamping device that is not sufficiently rigidly attatched.

4. Under instructions from the ground by the oversigned, ground resistance and

TRAVELER	PLACE VISITED
Andrew N. Smith Omega	Haiku, OTCC MTDP C

SUBJECTS DISCUSSED (Continued)

current to ground at the P-6 anchor point was measured by the inspection team. A Wenner-4-electrode array using a Biddle Megger comprised the ground measurement, while the current was determined by means of clamp-on A.C. ammeters. Grounding resistance was approximately 10 ohms, a value consistent with the configuration of the grounding connections used at the anchorage and the conductivity measured on the ridge at Haiku by the oversigned in 1965. The haliard ground return current at 10.2 kHz was variously reported as ½,2, and 8 amperes; the small value is invalid, based on a description of the set-up furnished by the inspection team later in the week. The 2 vs 8 ampere discrepancy is unexplained at present, and there is no a priori reason to prefere one over the other. The two values were obtained from two different meters supposedly held in a similar configuration. Both meters were calibrated by comparison with a Pearson toroidal current transformer at 10.2 kHz: with the cooperation of the Coast Guard, entry was made to the connection from one of the transmitters to the dummy load, where calibration tests were carreid out in the range of 5 to 13 amperes. The meters were self consistent to within relative to the Pearson to within 20%, one reading high, the other low; while fairly large, the 37% discrepancy between the ~~two~~ average of the two meters was consistent across the range, and was never large enough to account for the 2 to 8 ampere diffefence obtained on the ridge. It is likely that a value of the order of 5 amperes is reasonable, but the check should be rerun, using the calibration factors now known for the meters.

The significance of this grounding resixtance threefold. The first aspect is ~~is not so much that during~~ a 10,000 ampere pulse, the anchorage can be 100 kV above a reference located at infinity so much as local variations in potential in the soil immediately around the anchorage, because of the phhysical distribution of the rods, can be substantial if not actually dangerous from the possibility of local arcing along concrete-soil interfaces because the block is not on an equipotential surface. This aspect of the grounding layout is perhaps worth some improvement. The second aspect of the grounding resistance is that if all anchorages are similar, then there is about $(5)^2 \times 10 \times 12 = 3000$ watts of RF power loss in the termination resistance of the halyard system. This represents about 2% of the loss budget for the antenna and perusal of the design documentation does not reveal that this was taken into accout. Along with the neglect of termination loss in the radial ~~wire~~ ground system, this is an additional factor has prevented the present installation from achieving its design goal of 10 kW radiated. Finally, there was some concern that the grounding resistance may have some effect on the response of the antenna structure to a surge, and thus determine the magnitudes of the surface gradients so developed and so have significance relative to possibility of damage to accessory equipment mounted on the cable. This aspect is probably totally negligible, because the surge impedance of the halyard cable looking from the insulator location toward the ancgorage is about 550 ohms, while looking along the active span from the insulator toward the feed point it is about 620 ohms. A ten ohm termination of such a line is only negligibly different from a one ohm termination except for attenuation effects on surge spectral components for which the line lenght is very close to a quarter wave; therefore in gross effects the differences are hardly noticeable even if the comparison is made to a line terminated in zero resistance. Therefore the quality of ground offered the haliards by the roughly ten-ohm termination for lightning surges and control of gradients resultig therefrom is fairly good.

5. Because of the difficulty and uncertainty of gaining access to the span achorages to carry out direct visual inspection, due to combined aspects of terrain, weather,

TRIP REPORT – CONTINUATION
11ND-GEN-5050.2 (12-65) 0190-029-5200

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Andrew N. Smith	Omega Haiku, OICC MIDPAC

SUBJECTS DISCUSSED (Continued)

equipment and personnel offloading, aircraft flight characteristics, a partial inspection was carried out from a hovering helicopter by use of binoculars and telephoto cameras. This was done for spans 6, 4, and 3, with most attention being concentrated on the vibration damper group on the active portion of the span closest to the insulator. It was found that detail as small as spots on individual strands, and the strands themselves, could be easily resolved through 7-power binoculars from a distance of 80 feet. Using ASA 64 emulsion Ektachrome, in an effective 430 mm focal length lense with effective f-stop of f9, and an exposure time of 1/500 seconds, fairly good photographs were obtained of the damper groups and cable between members of a group such that individual strands could just be resolved. The limitation of resolution seemed to be relative motion of the camera and object; it was concluded that photographic inspection using ASA 160 or 400 with a similar focal length but with correspondingly higher shutter speeds with the same stop opening in similar strong sunlight conditions should result in the ability to resolve as much detail photographically as visually with 10-power binoculars. The limit of resolution under these circumstances should be blemishes and defects of moderate contrast with the wire, having diameters or widths of the order of 1/8 inch. This is not sufficient to enable detection of small scratches or pits from small arcs, but it permits seeing rust streaks, large chafe marks, dirt spots on insulators, and the residue of packing material stuck to the surface of the damper weights, discoloration due to weathering and corrosion. No evidence was seen during the inspection of effects in any way attributable to electrical arcing. No damper or group was observed to be or to have been in contact with the cable except where bonded by the clamping devices.

6. Conclusions from inspections carried out during the reporting period combined with data gathered from controlled testing using the high voltage facility at Lualualei are as follows:

Vibration dampers are causing no arcing or mechanical abrasion after installation; some of the clamps may have been applied in a manner that abraided the cable at the clamp location; dampers should be removed carefully, cable inspected, and damper reinstalled, after suitable cable surface treatment.

Visibility markers are not nearly as visible as insulators, the markers are susceptible to burn damage as a result of corona flares caused by lightning strikes and thereafter may progressively fail with application of operating RF fields; they are attached by clamps that are not sufficiently rigid and that cause local rapid wear and abrasion of the wire surface from mechanical vibration; the markers should therefore be removed.

Periodic inspections of the spans if required can be carried out by helicopter using visual aids such as high quality binoculars or telephoto camera, but only major defects are likely to be detected in this way.

Such damage as exists on the cable of span 6 subjected to above inspection can not be attributed to electrical effects or to chafing by vibration damper wieghts, but is due to some other undetermied mechanical cause which apparently took place during erection.

Spans 1 and 6 should be completely inspected visually by the present travelling cage technique; both Pali and Kahuku haliards of all other spans should be inspected by bosuns chair if possible. Ground resistance measurement and ground return current should be measured on at least 4 other anchorages of the Pali 6; the latter should be repeated.

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